LPR Contaminant Mapping Approach

ANCHOR QEA

Presentation to EPA

March 11, 2015

EPA Region 2 Office

620511

Outline

- Objectives of the mapping
- Predictability of sediment contaminant concentrations (patterns relate to bed evolution)
  - Focus on 2,3,7,8-TCDD, but most other contaminants show comparable patterns
- Partitioning the river to account for geomorphological influences on concentrations
- Approach to LPR contaminant mapping
  - Precedent for Using Thiessen Polygon Interpolation for RI/FS Work
  - Apply Thiessen Polygon interpolation within partitioned river

Objectives of the Mapping

- Approximately delineate the regions of high concentration to support the goal of characterizing nature and extent of contamination
- Provide an *approximate* (i.e., "FS Level") representation of sediment contaminant concentrations throughout the LPR
  - Needed to examine remedial alternatives
  - Needed to model contaminant fate and transport and bioaccumulation
- Objectives recognize that more refined mapping will be undertaken as part of remedy design

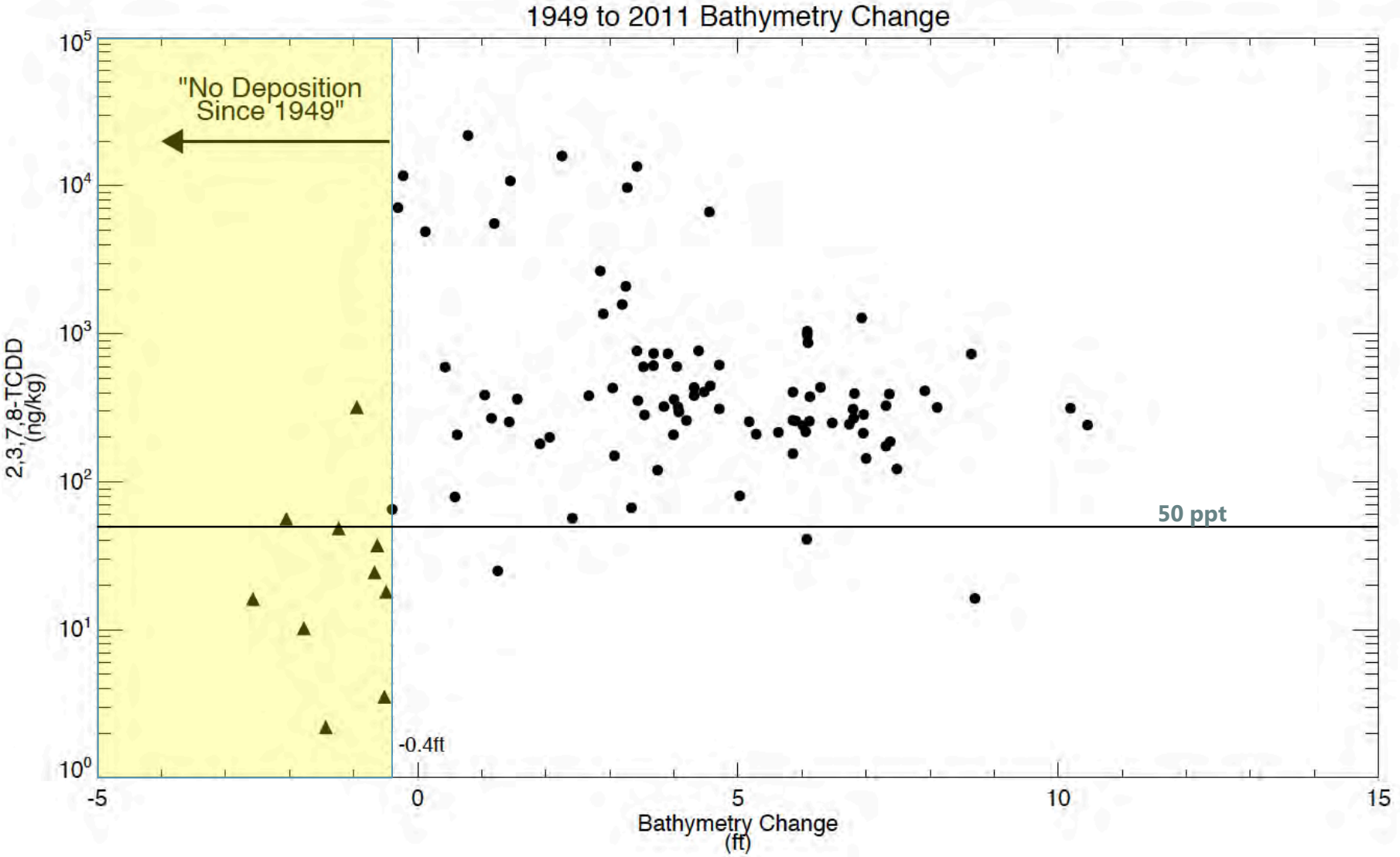
Data Used in the Mapping

Study Name	Years	Centroid	Data Counts					
			TCDD	Total PCBs	Mercury	HMW PAH	LMW PAH	Total DDx
Honeywell International Sampling Programs	2005, 2006	no	2	2	2	2	2	0
USEPA/MPI – High-Resolution Sediment Coring Program	2005, 2006, 2008	no	1	1	0	1	1	0
USEPA/MPI – EMBM	2007, 2008	no	18	18	18	18	18	9
Low-Resolution Coring Program	2008	yes	90	91	91	91	91	90
USEPA/MPI – Sediment Sampling Program	2008	no	10	10	17	10	10	10
Benthic Program Surface Sediment Sampling (2009)	2009	no	110	110	110	0	110	110
Benthic Program Surface Sediment Sampling (2010)	2010	no	21	21	21	0	21	21
River Mile 10.9 Characterization	2011	yes	54	54	54	54	54	54
Low-resolution Coring Program Supplemental Sampling Program	2012	yes	85	85	85	85	85	85
Tierra – Focused Sediment Investigation (RM 10.9)	2012	no	6	0	0	0	0	0
River Mile 10.9 Addendum A	2012	yes	15	15	15	15	15	15
Low-resolution Coring Program Supplemental Sampling Program 2	2013	yes	75	74	74	72	72	74

Most of the samples collected between 2008 and 2013

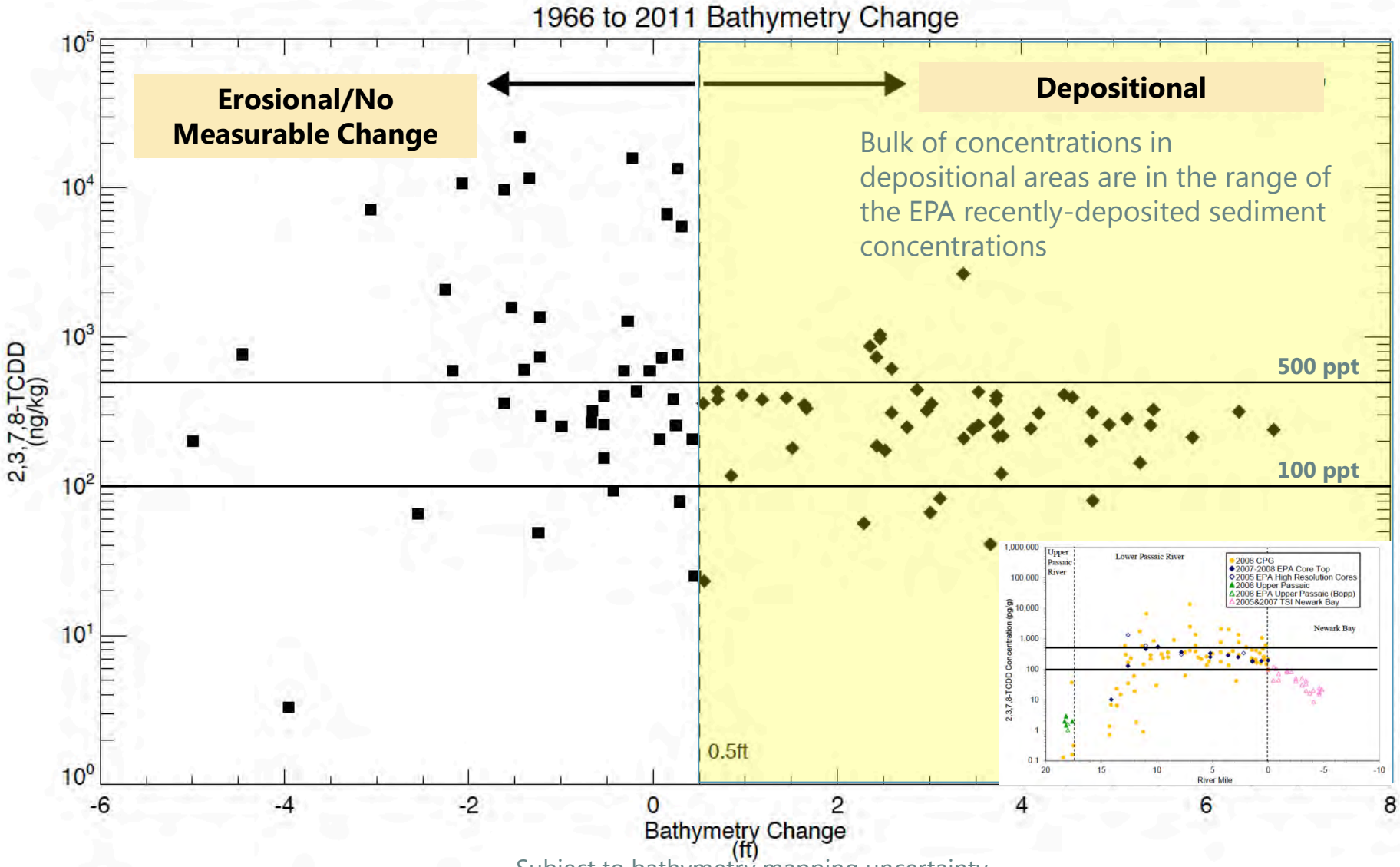
Channel Concentrations Relate to Erosion/Deposition History

As Expected, Channel Locations Lacking Post-1949 Sediments Have Low Concentrations



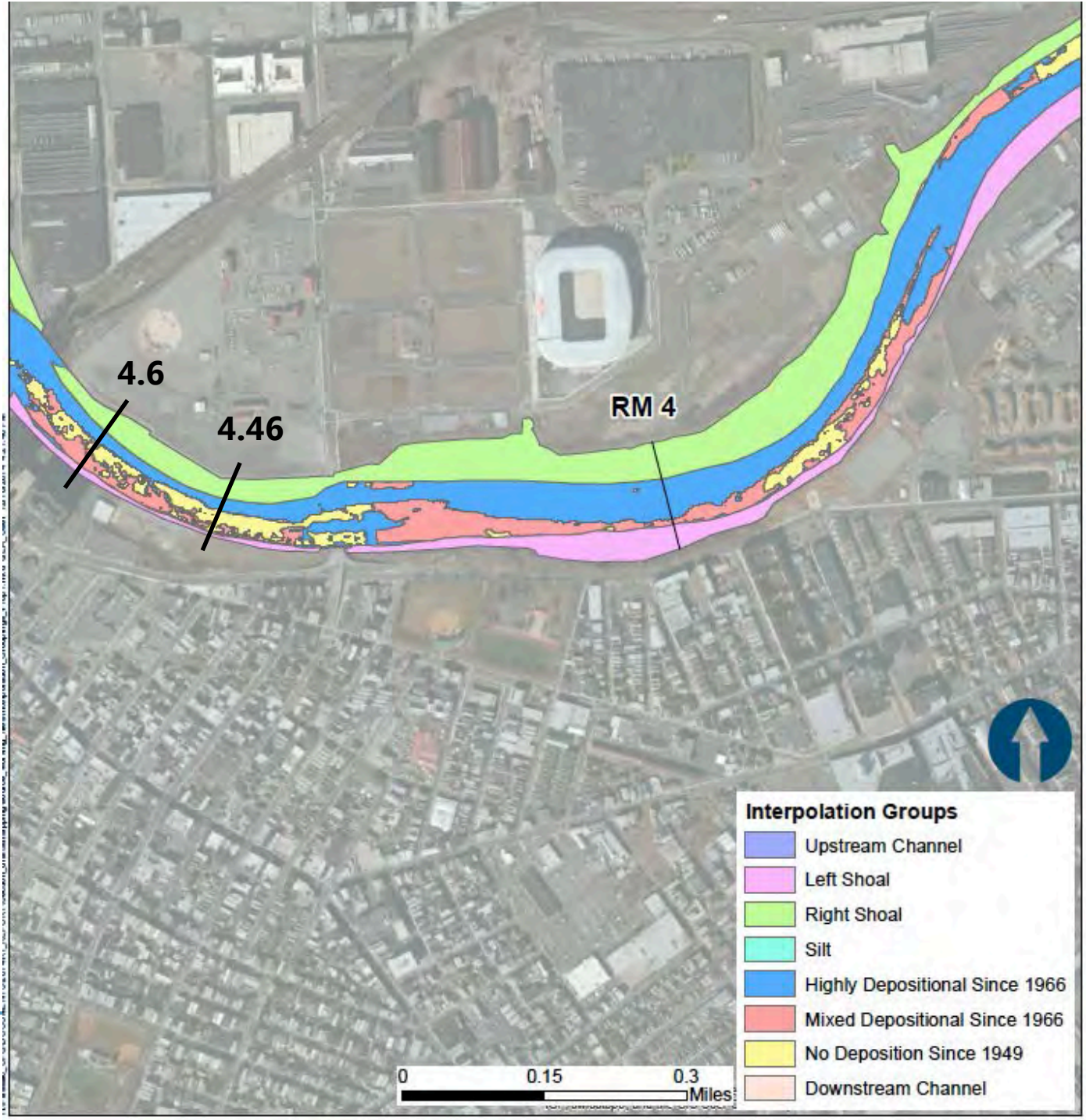
Subject to bathymetry mapping uncertainty

Highest Concentrations in Channel at Locations Having Post-'49 Sediments, But Erosion/No Change Since '66

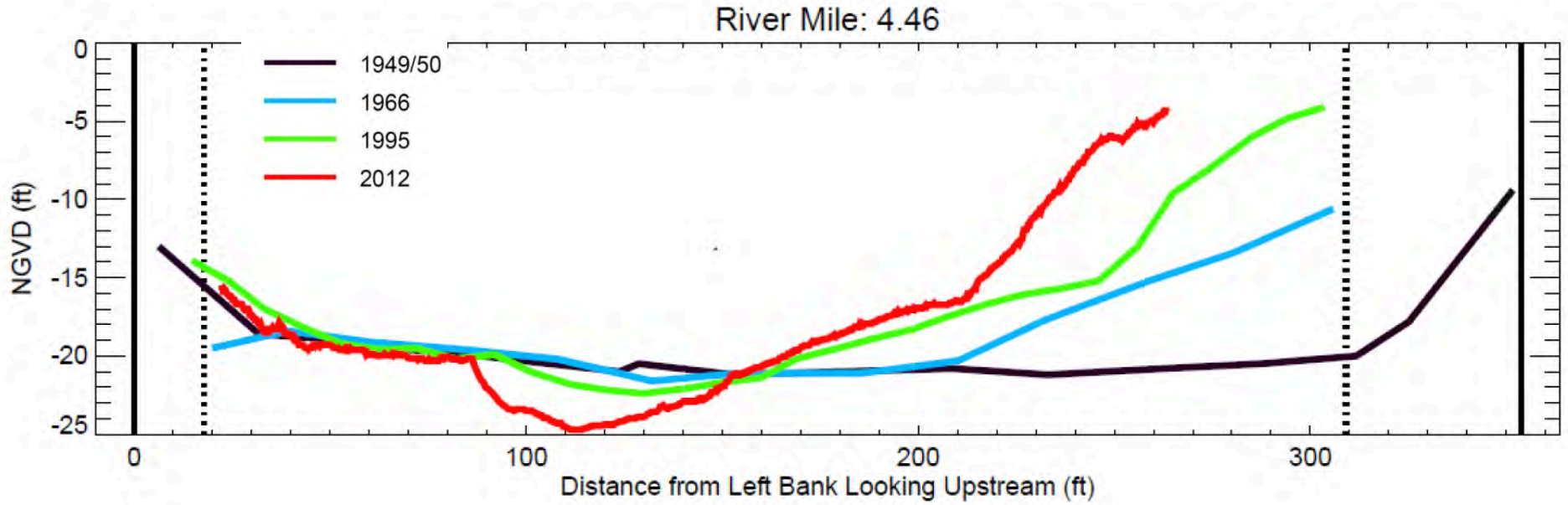


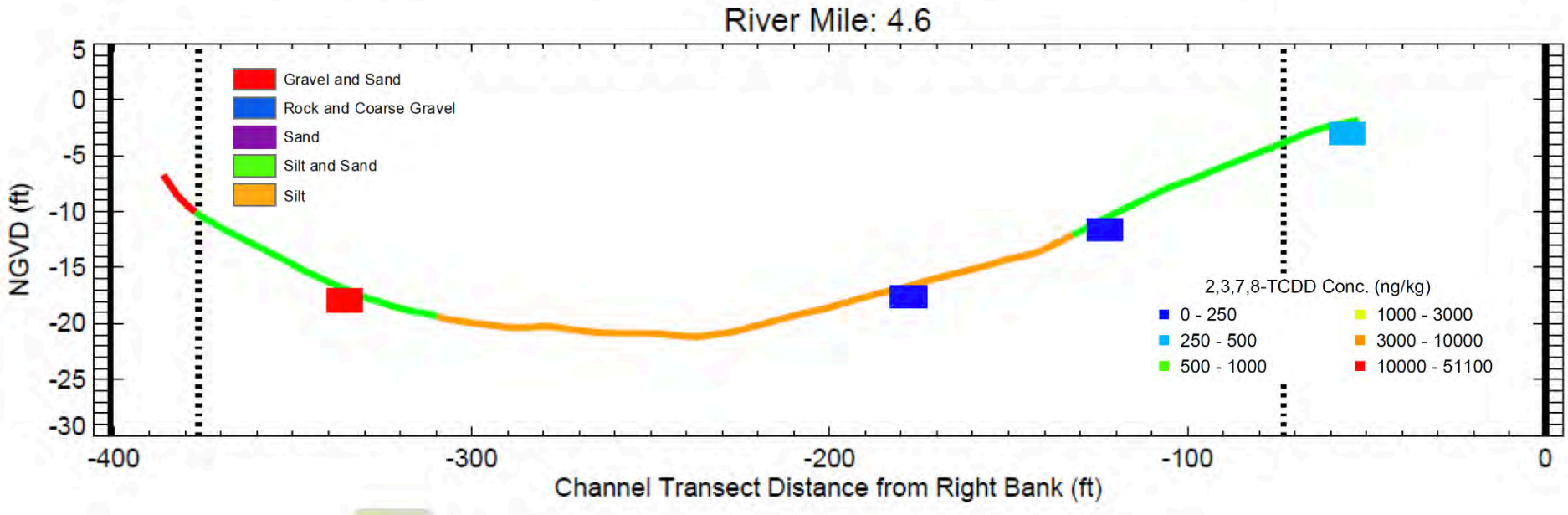
Subject to bathymetry mapping uncertainty

Transects to Examine Bed Evolution and Contaminant Concentrations



Example of Relationship Between Surface Sediment Concentration and Bed Evolution





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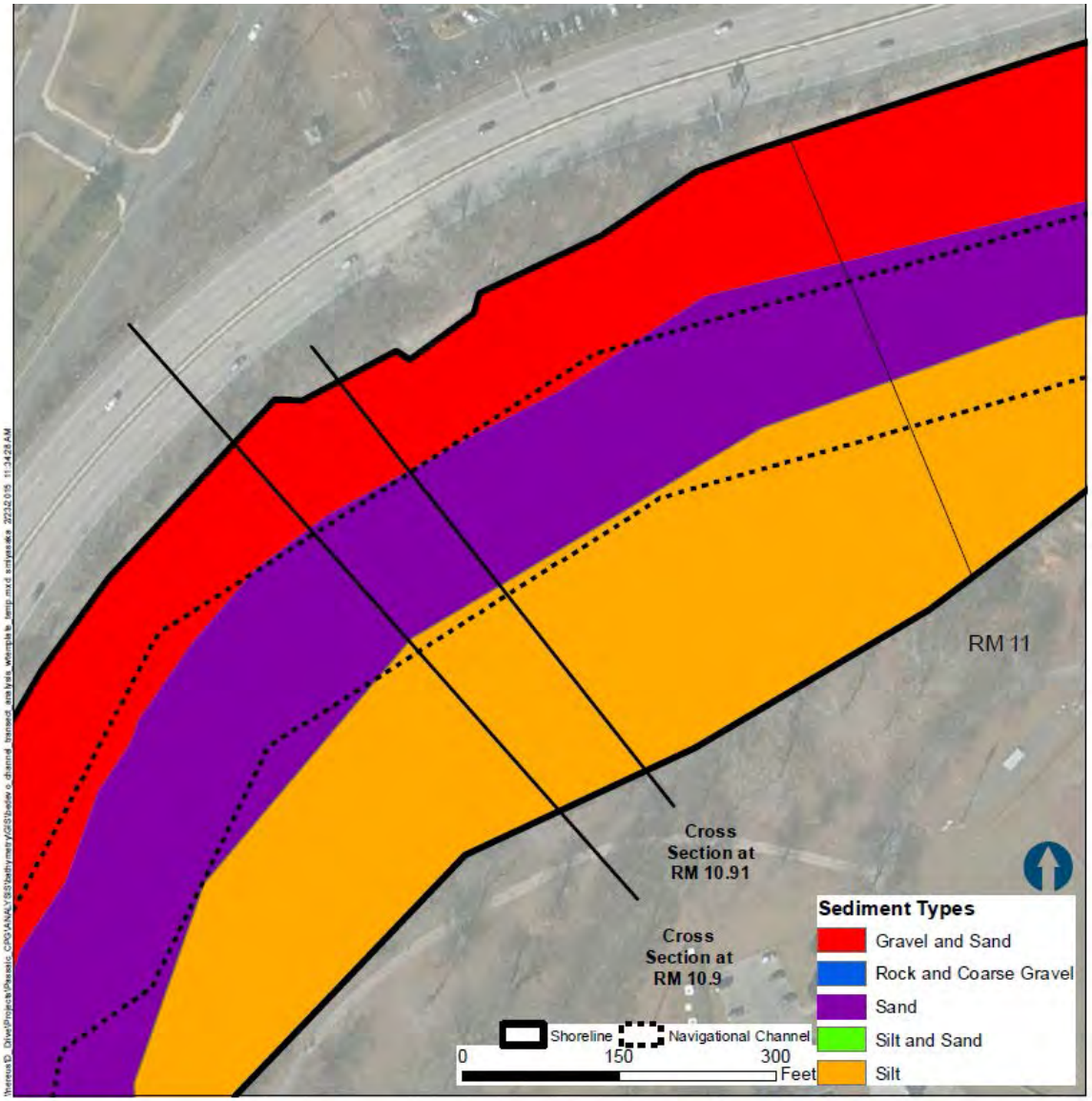
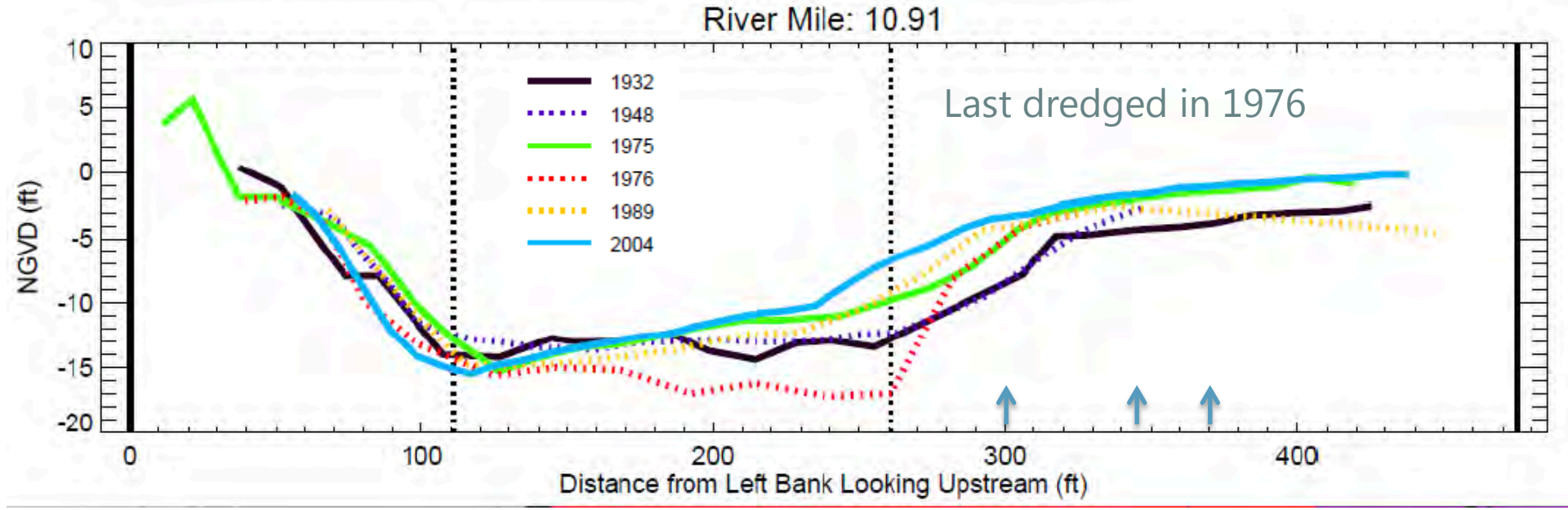
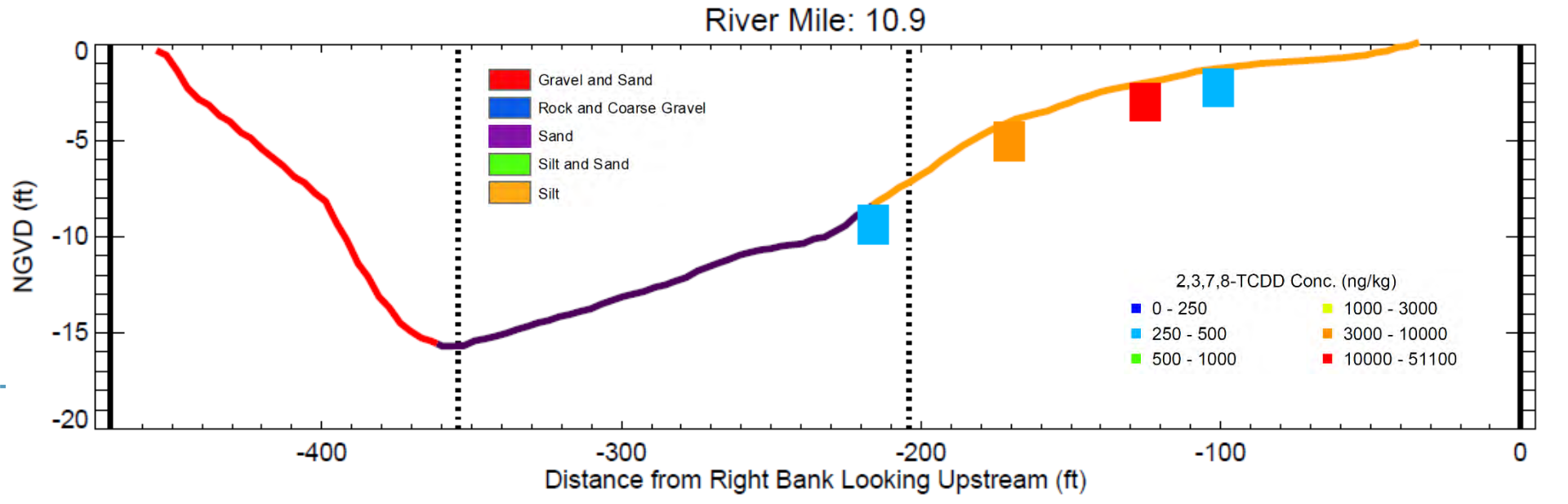
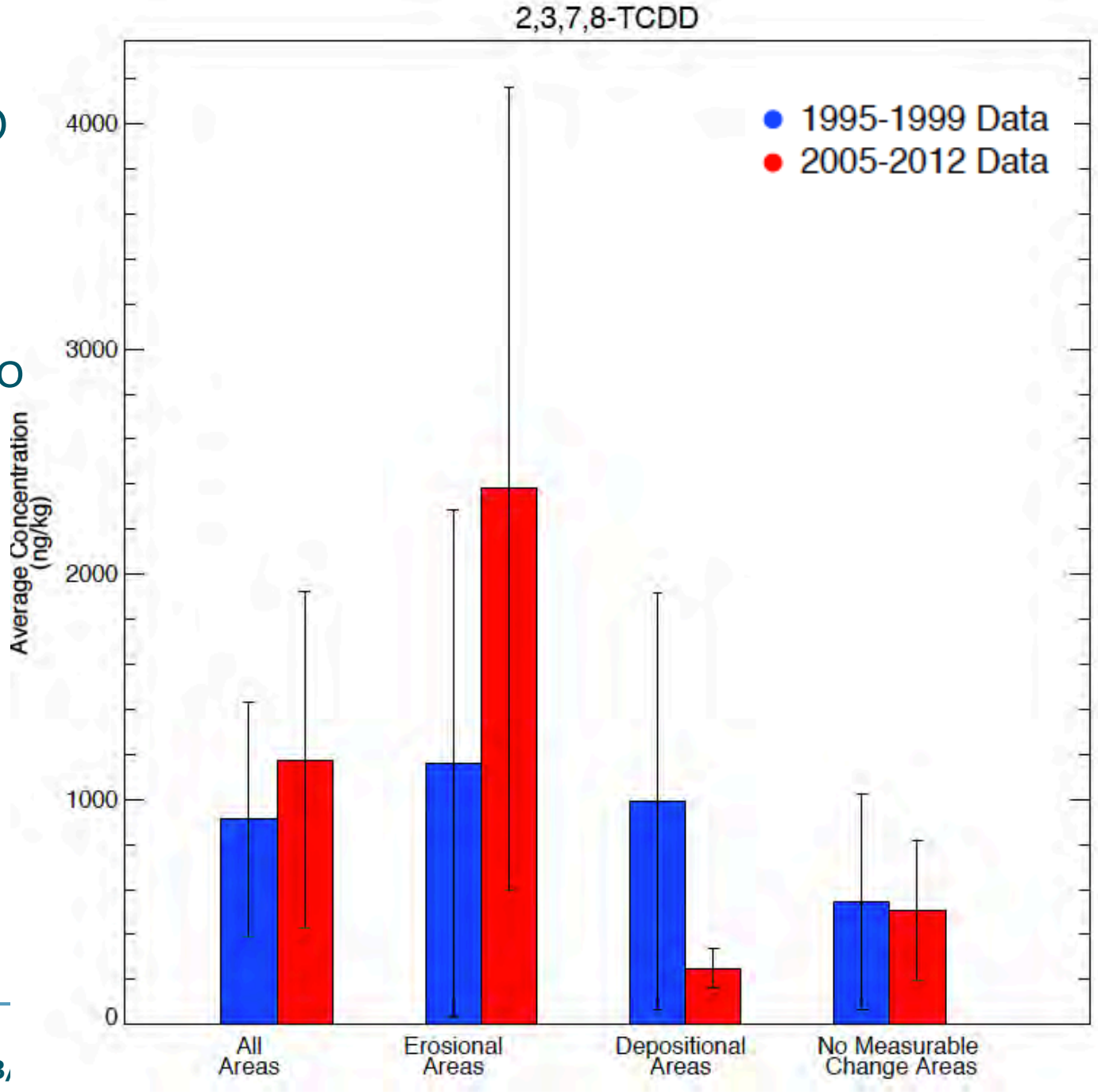


Example of Relationship Between Surface Sediment Concentration and Bed Evolution



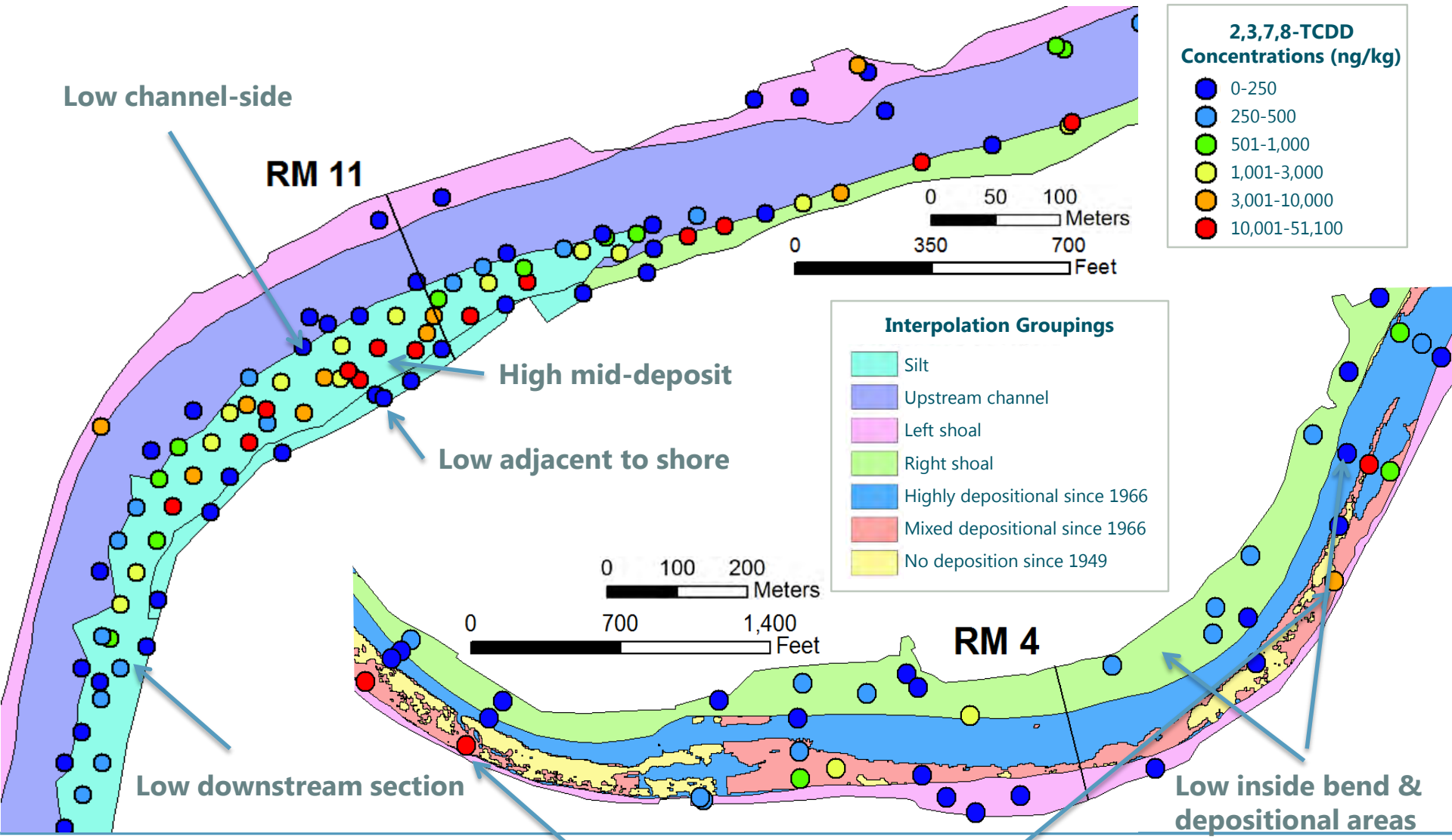


Surface 2,3,7,8-TCDD Changes Relate to Recent Erosion/Deposition



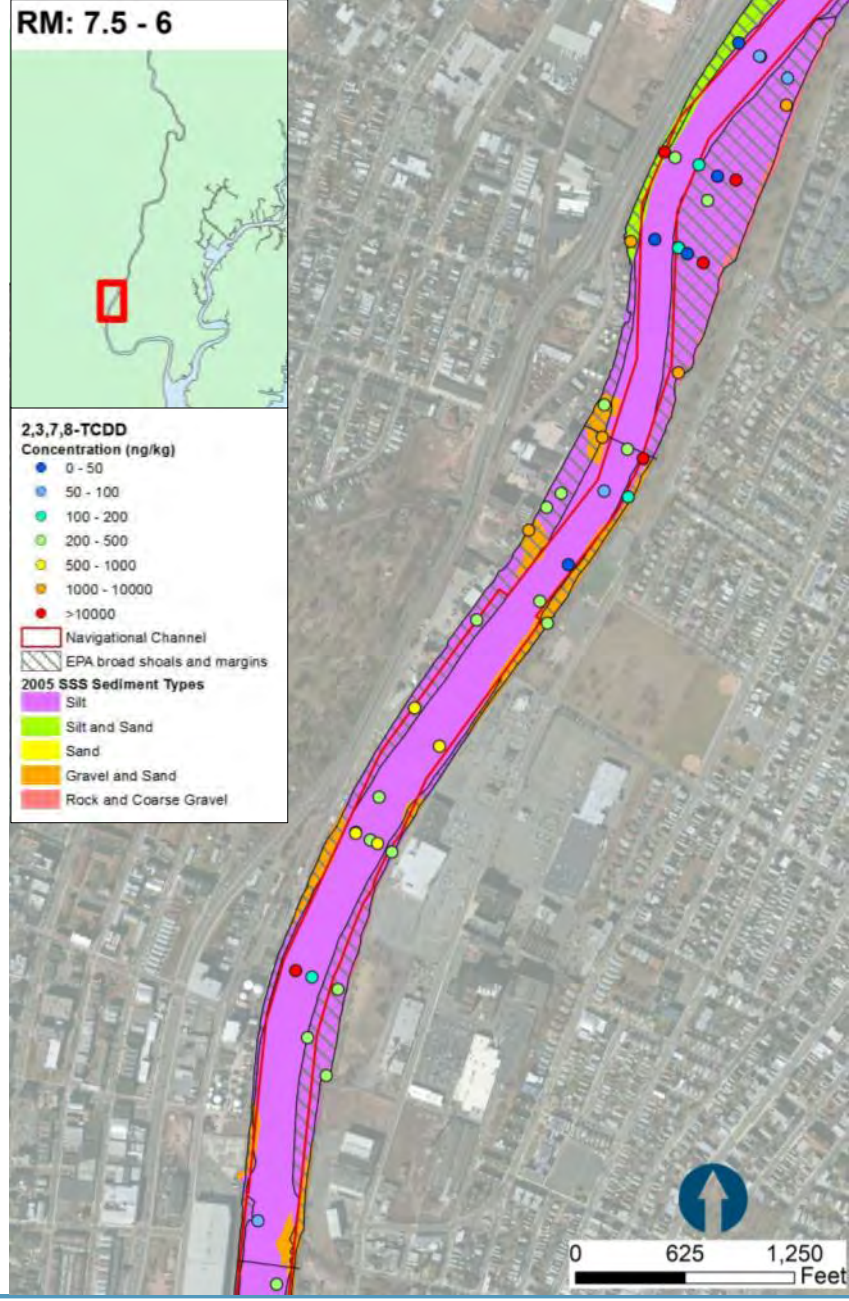
Local Patterns Exist

Patterns Exist at the Sub-Deposit Scale

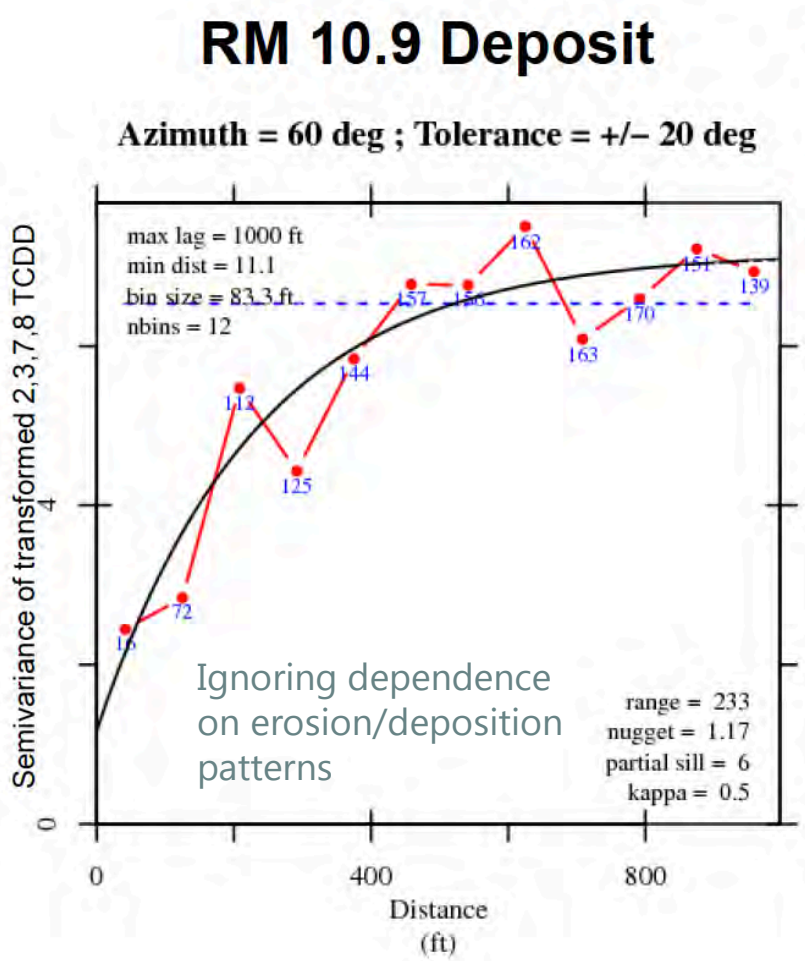


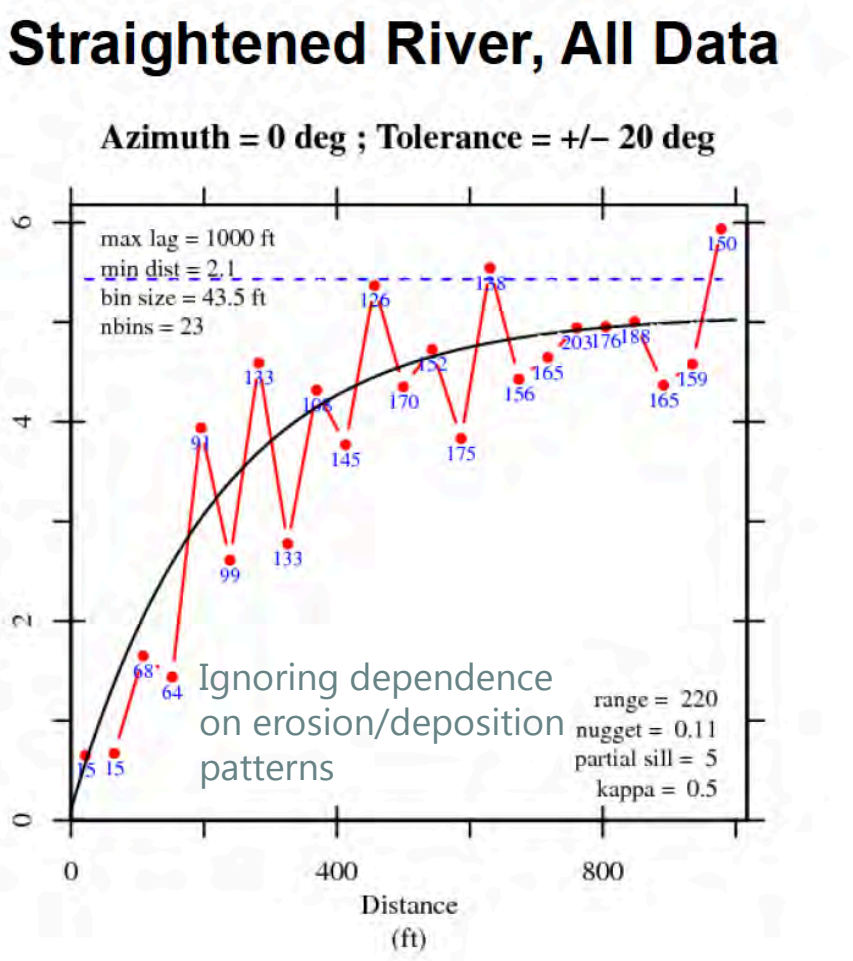
Along-River Correlation Within Deposits

- Cross-river gradients reflecting geomorphology

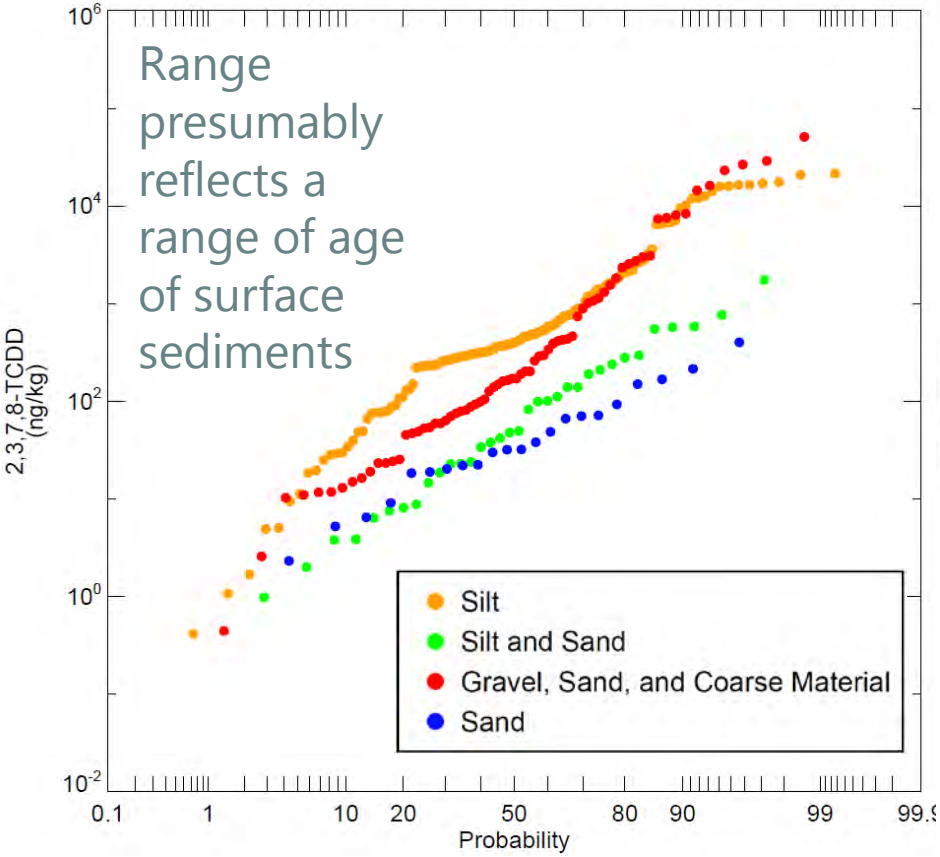


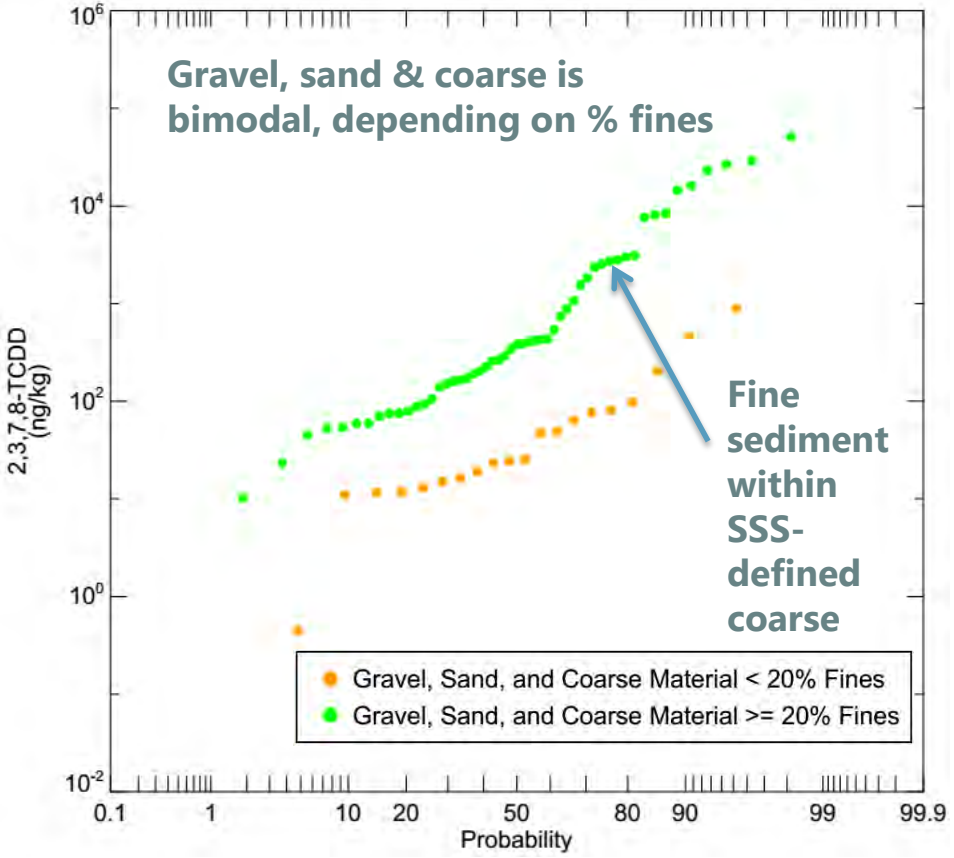
Variogram Shows Along-River Concentration Correlation on the Scale of Several Hundred Feet





RM 7.8-14 Concentrations Vary Among the Sediment Types

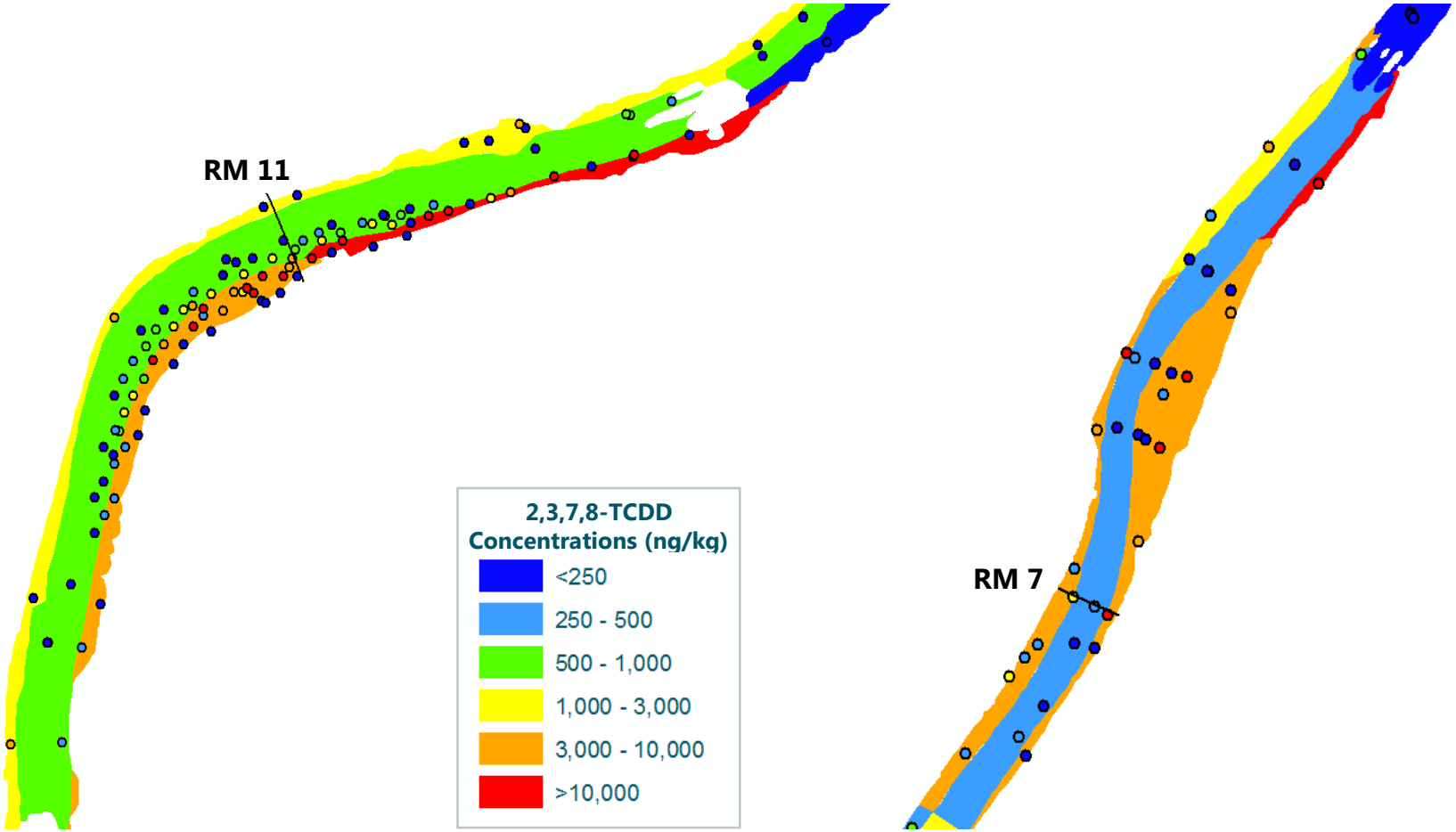




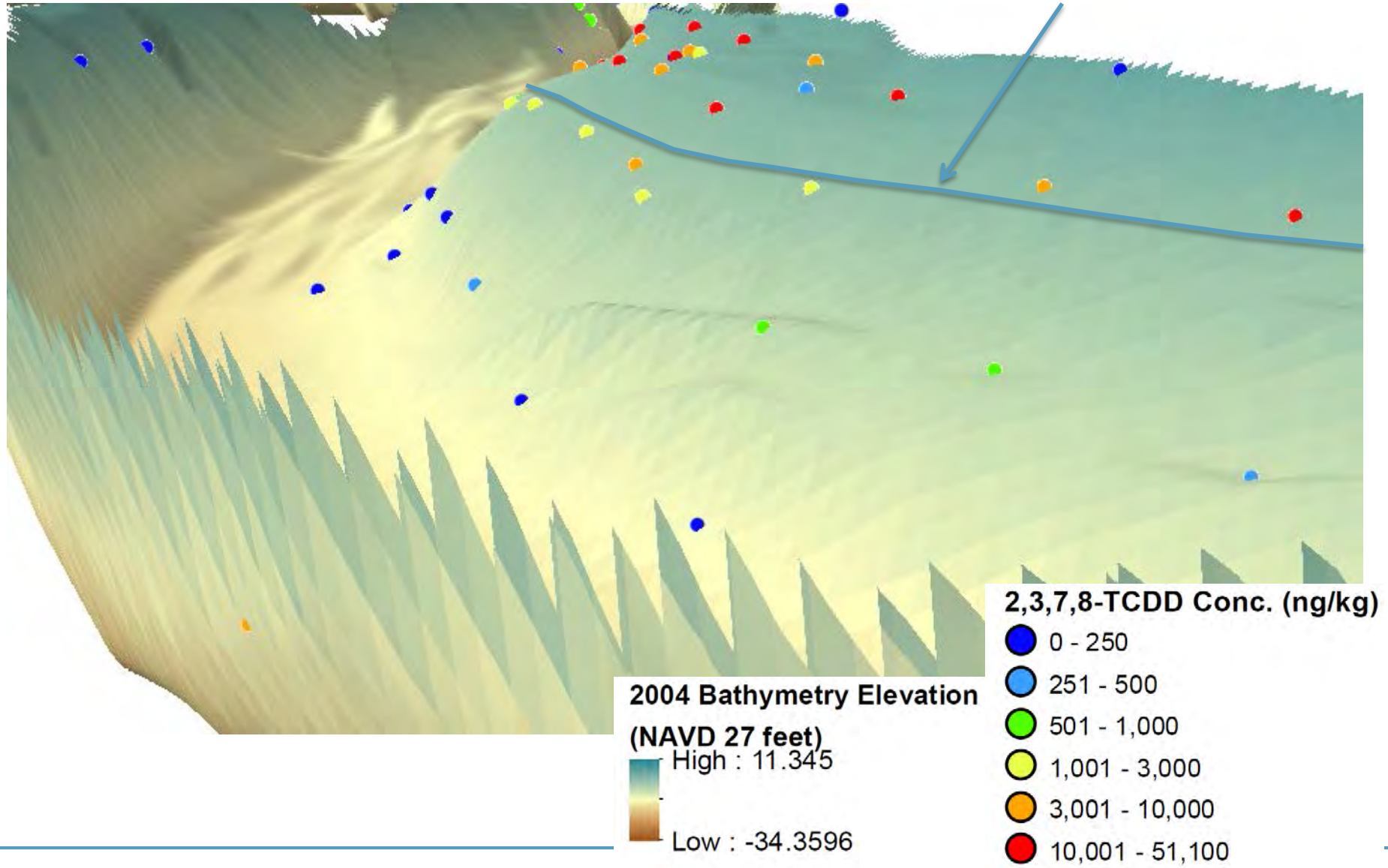
Note: The 'Gravel, Sand and Coarse Material' category combines both 'Gravel and Sand' and 'Rock and Coarse Gravel' 2005 Side Scan Sonar classifications.

Broad-Scale Averaging (even within geomorphic units) Does Not Take Account of the Evident Patterns

Disadvantage of Averaging is Seen When Comparing Averages to the Data

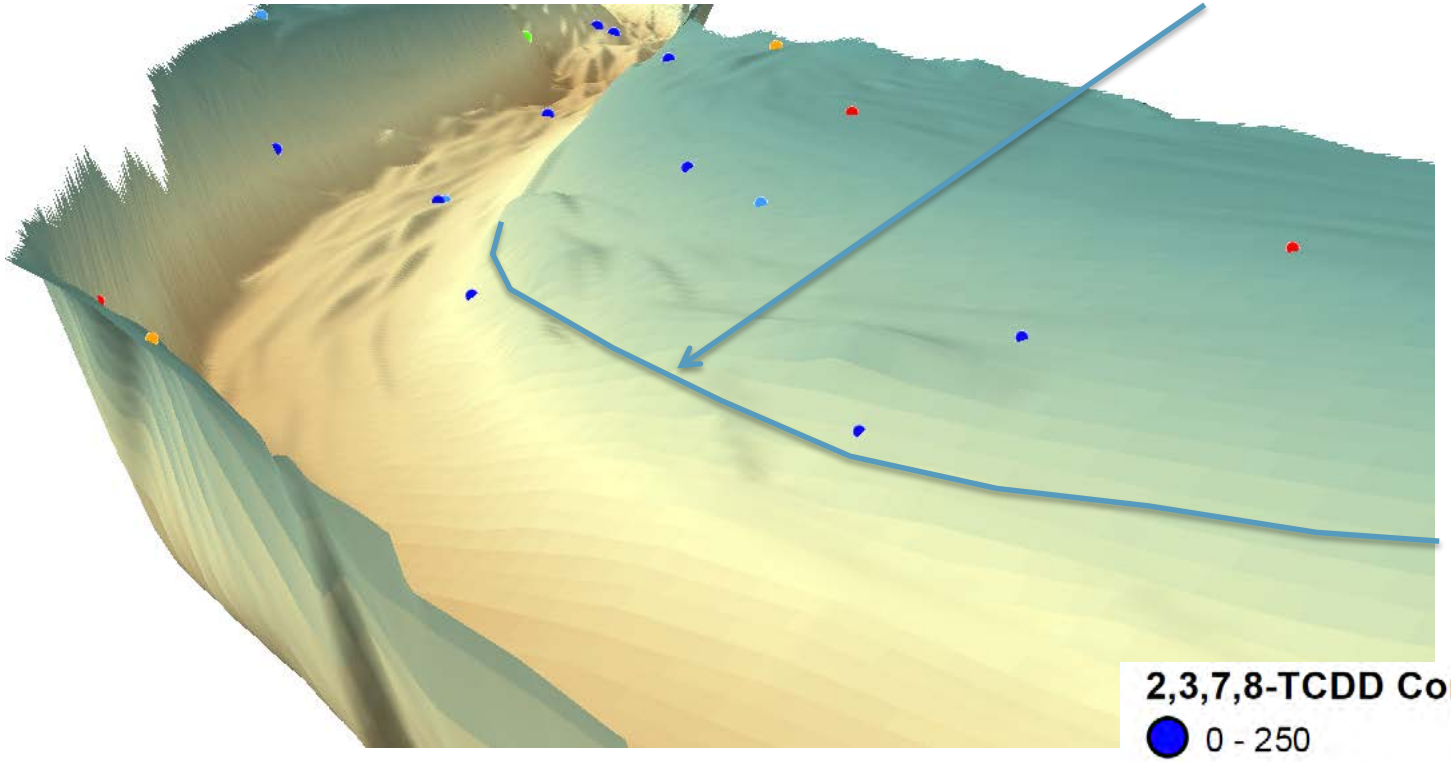


RM 10.9 – 10x vertical exaggeration



RM 7.5 – 10x vertical exaggeration

Approx. Boundary of EPA Geomorphic Unit



2004 Bathymetry Elevation (NAVD 27 feet)

High : 11.345

Low : -34.3596

2,3,7,8-TCDD Conc. (ng/kg)

- 0 - 250
- 251 - 500
- 501 - 1,000
- 1,001 - 3,000
- 3,001 - 10,000
- 10,001 - 51,100

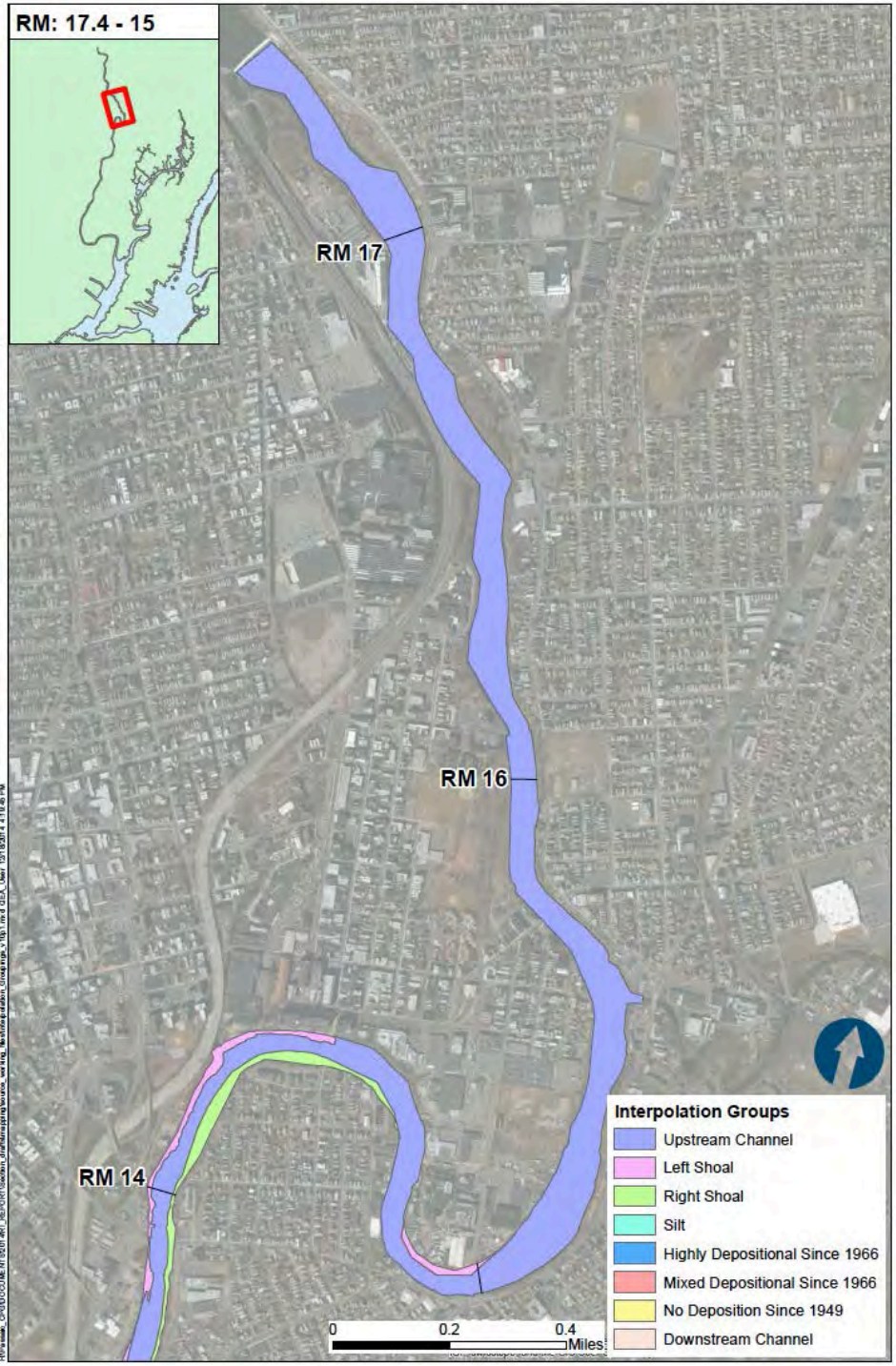
River Stratified to Account for the Concentration Patterns

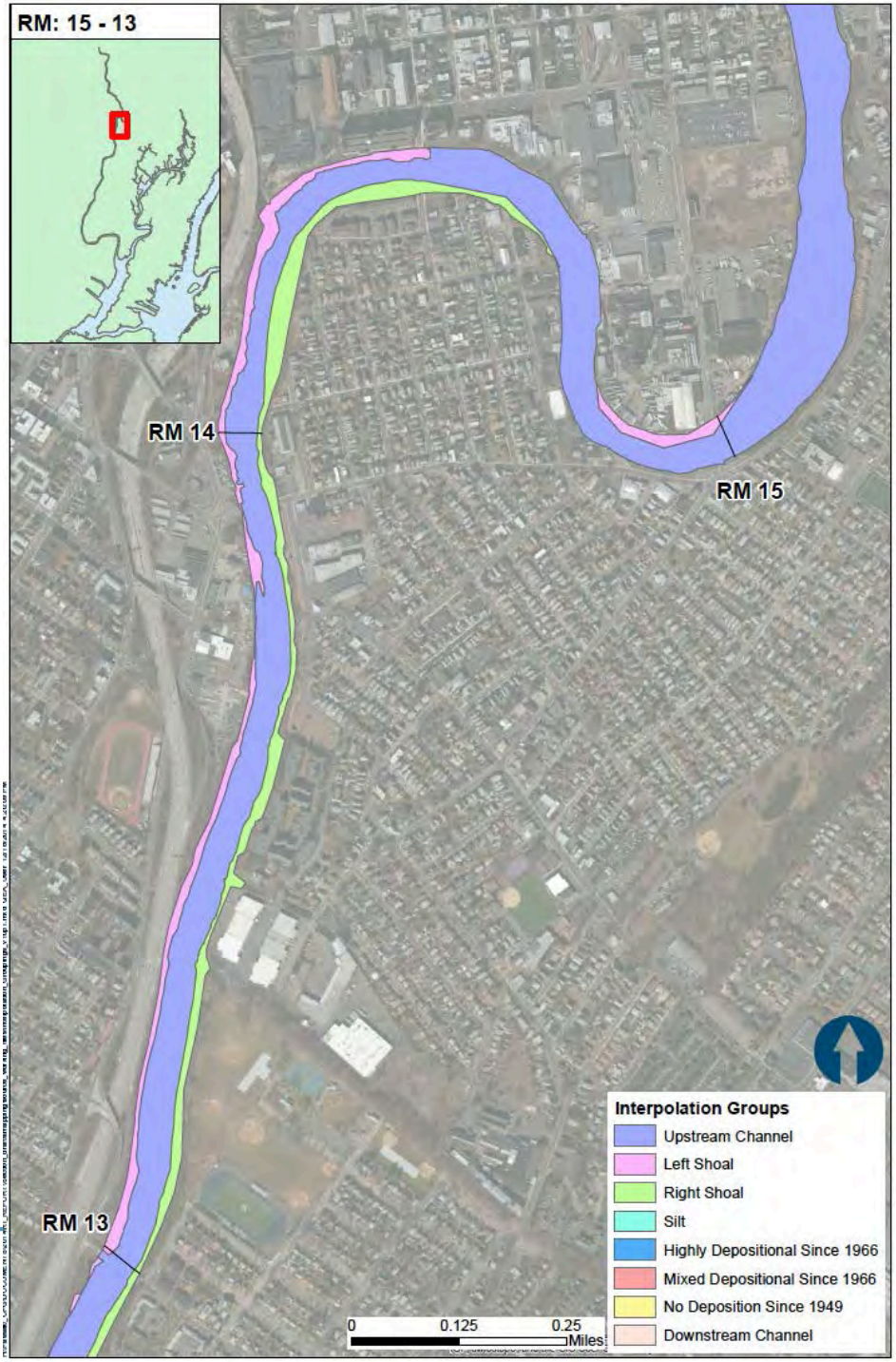
Information Exists to Appropriately Partition the River

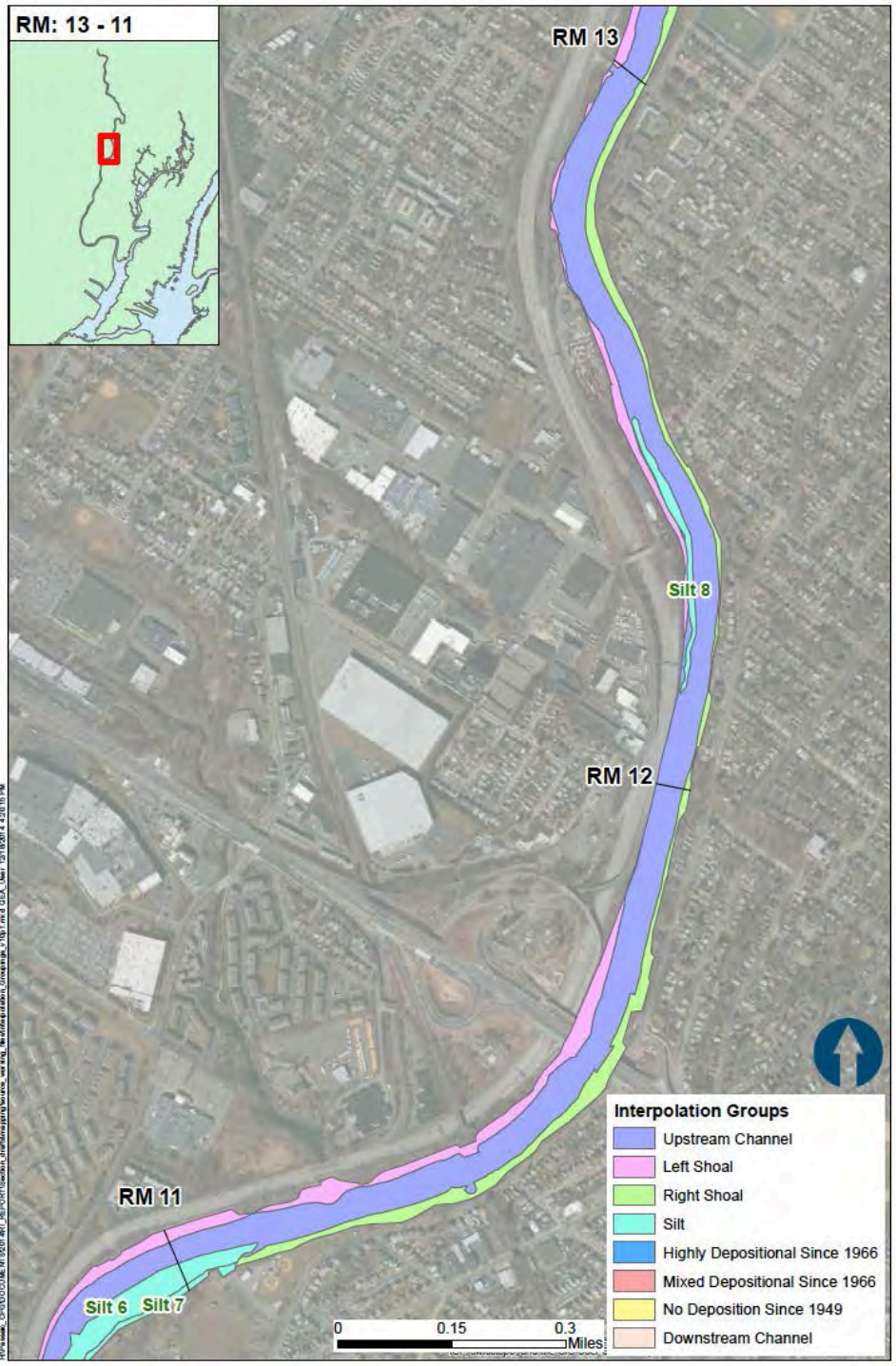
- Bathymetry measurements allow separation of shoals and channel
- Side-scan sonar and probing map sediment type
- Bathymetric differencing between surveys provides means to approximately identify net erosion/deposition patterns

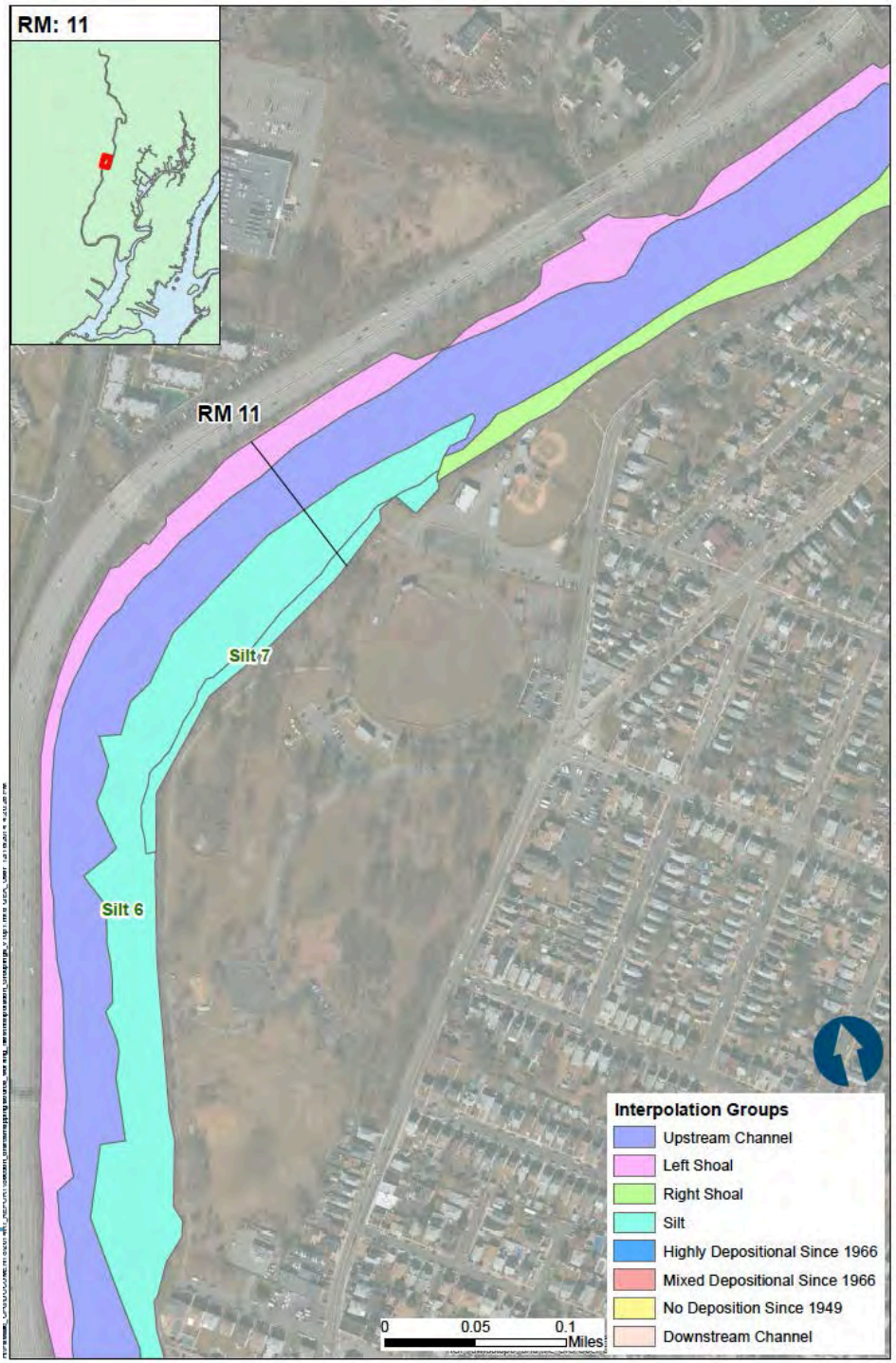
Acres for the Various Partitions of the River

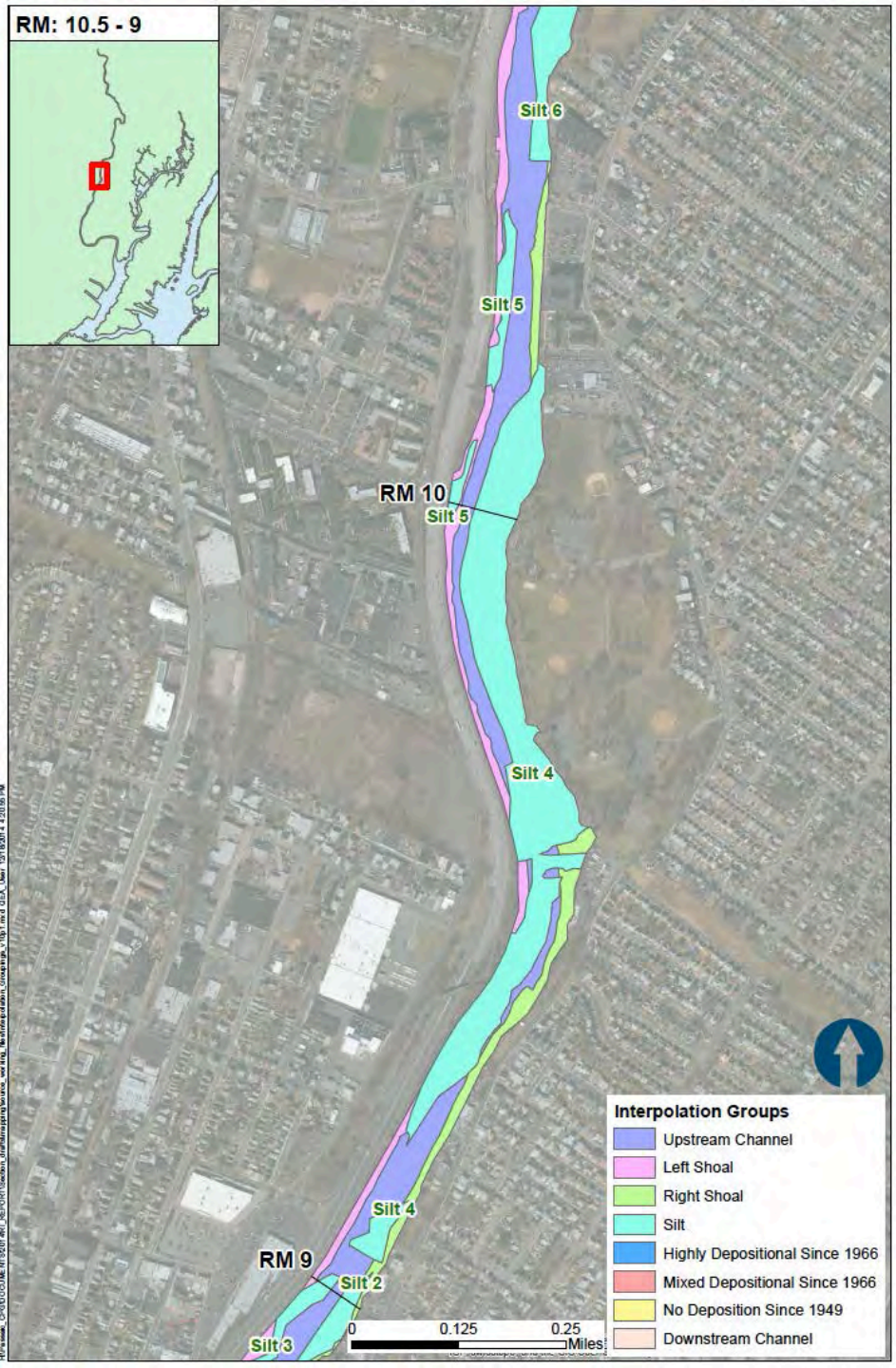
	RM 0 – RM 8	RM 8 – RM 14	RM 14 – RM 17.6
Shoal	377	57	10
Non-dep channel	19		
Mixed dep channel	50		
High dep channel	112		
Silt deposits	3	40	
Channel		119	106
RM10.9 Silt Deposit		13	
Downstream Channel	110		


RM: 17.4 - 15
RM 17
RM 16
RM 14
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.2
0.4
Miles

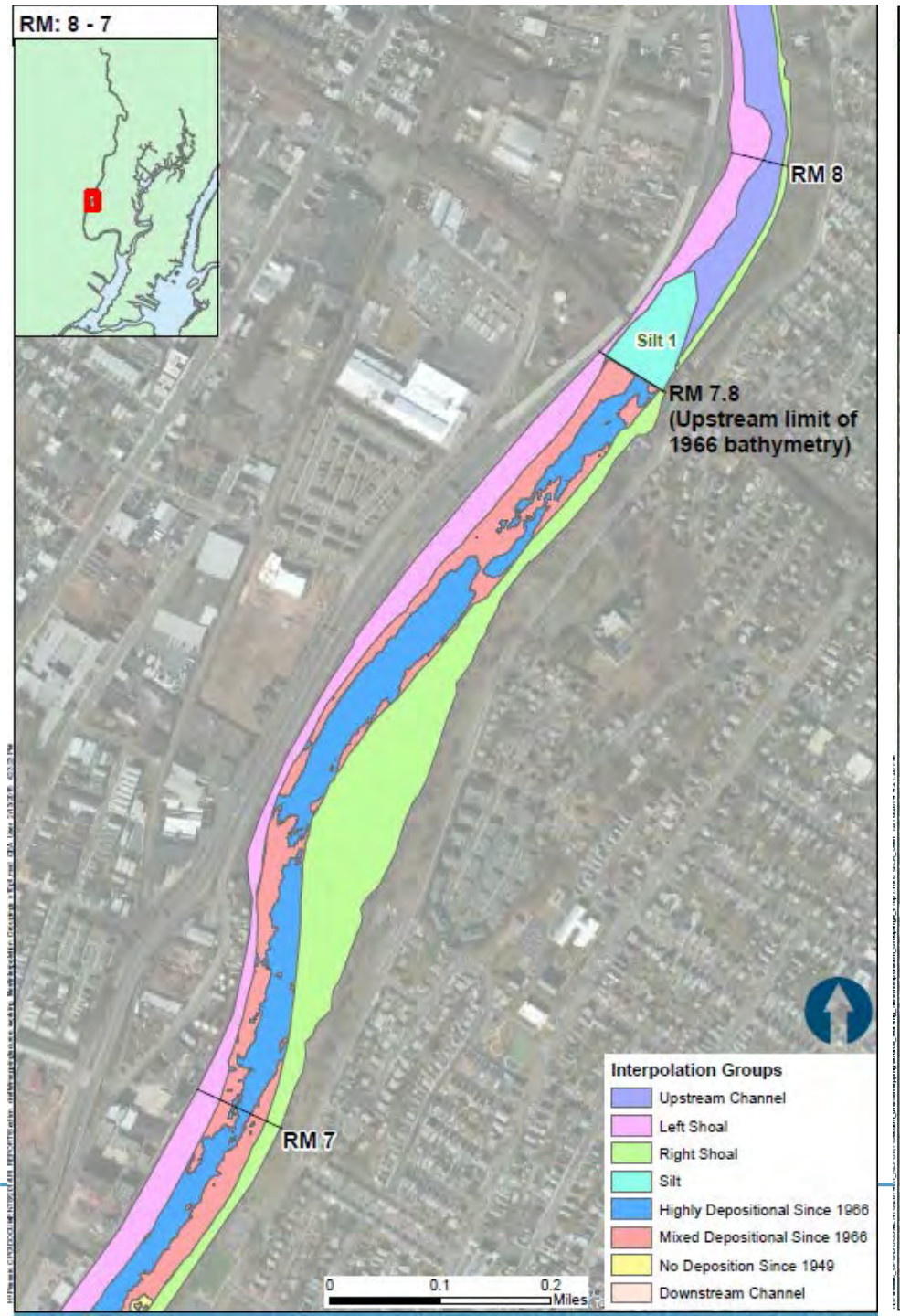

RM: 15 - 13
RM 14
RM 15
RM 13
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.125
0.25
Miles

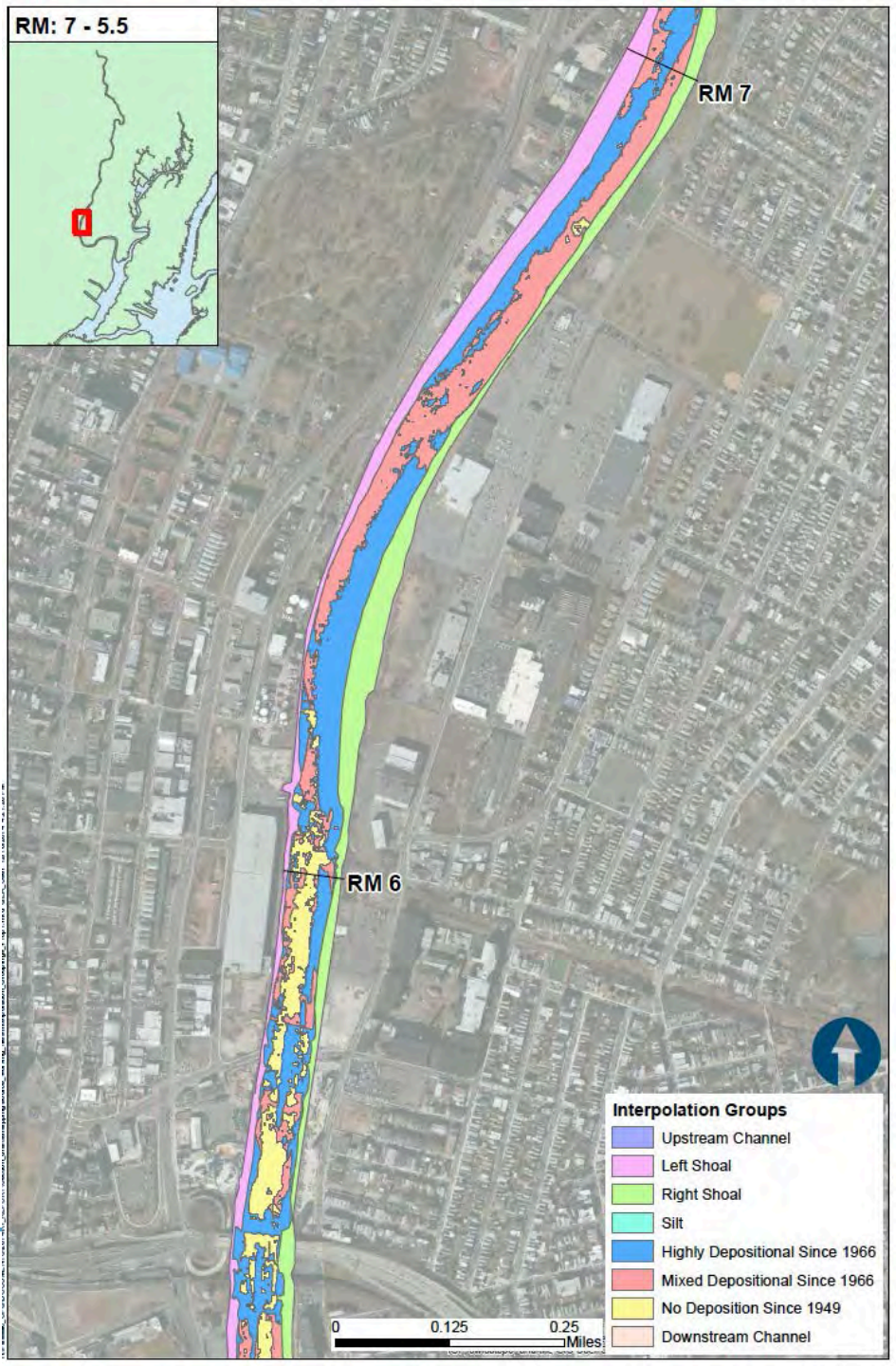

RM: 13 - 11
RM 13
Silt 8
RM 12
RM 11
Silt 6
Silt 7
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.15
0.3
Miles

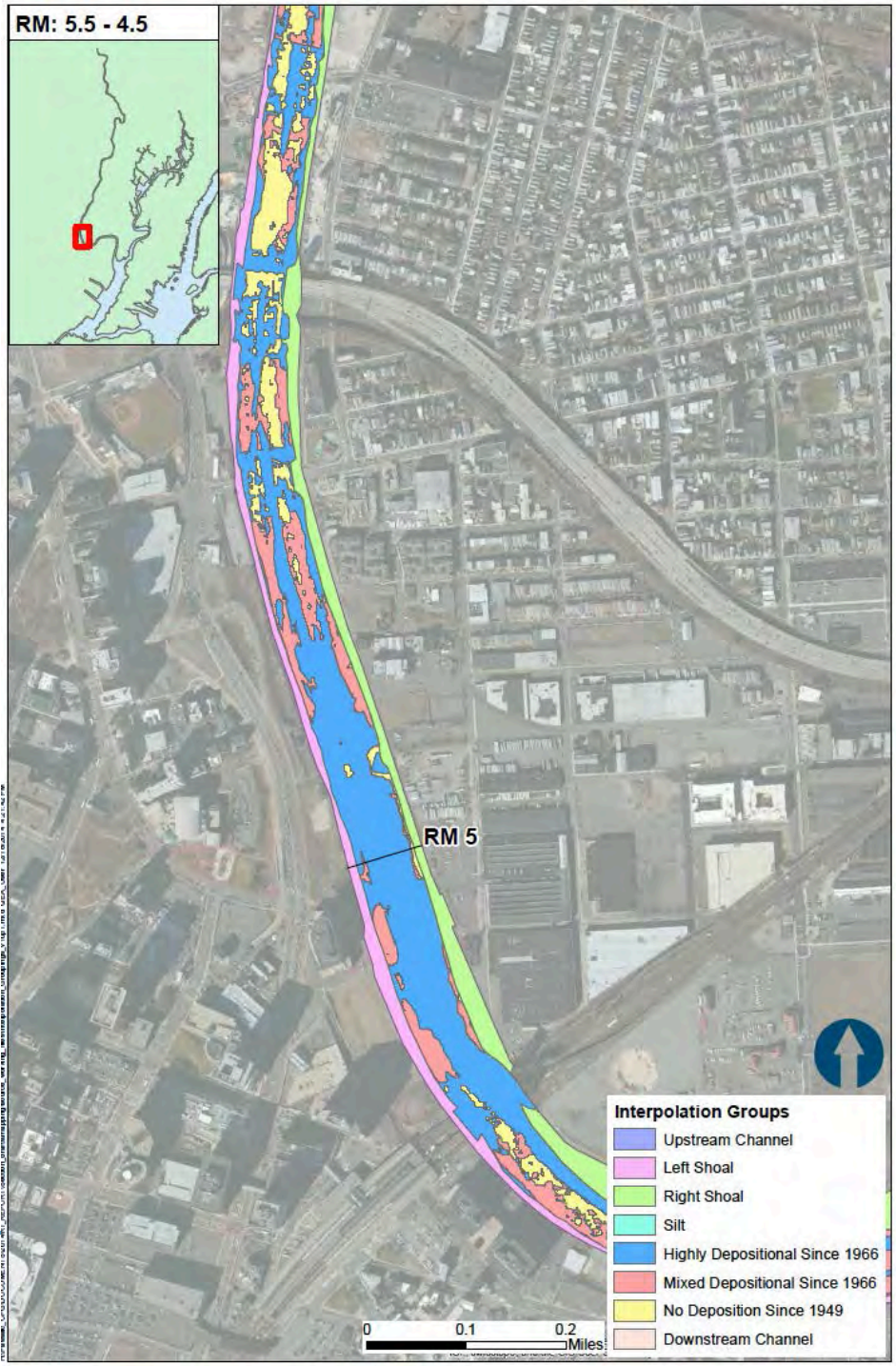

RM: 11
RM 11
Silt 7
Silt 6
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.05
0.1
Miles

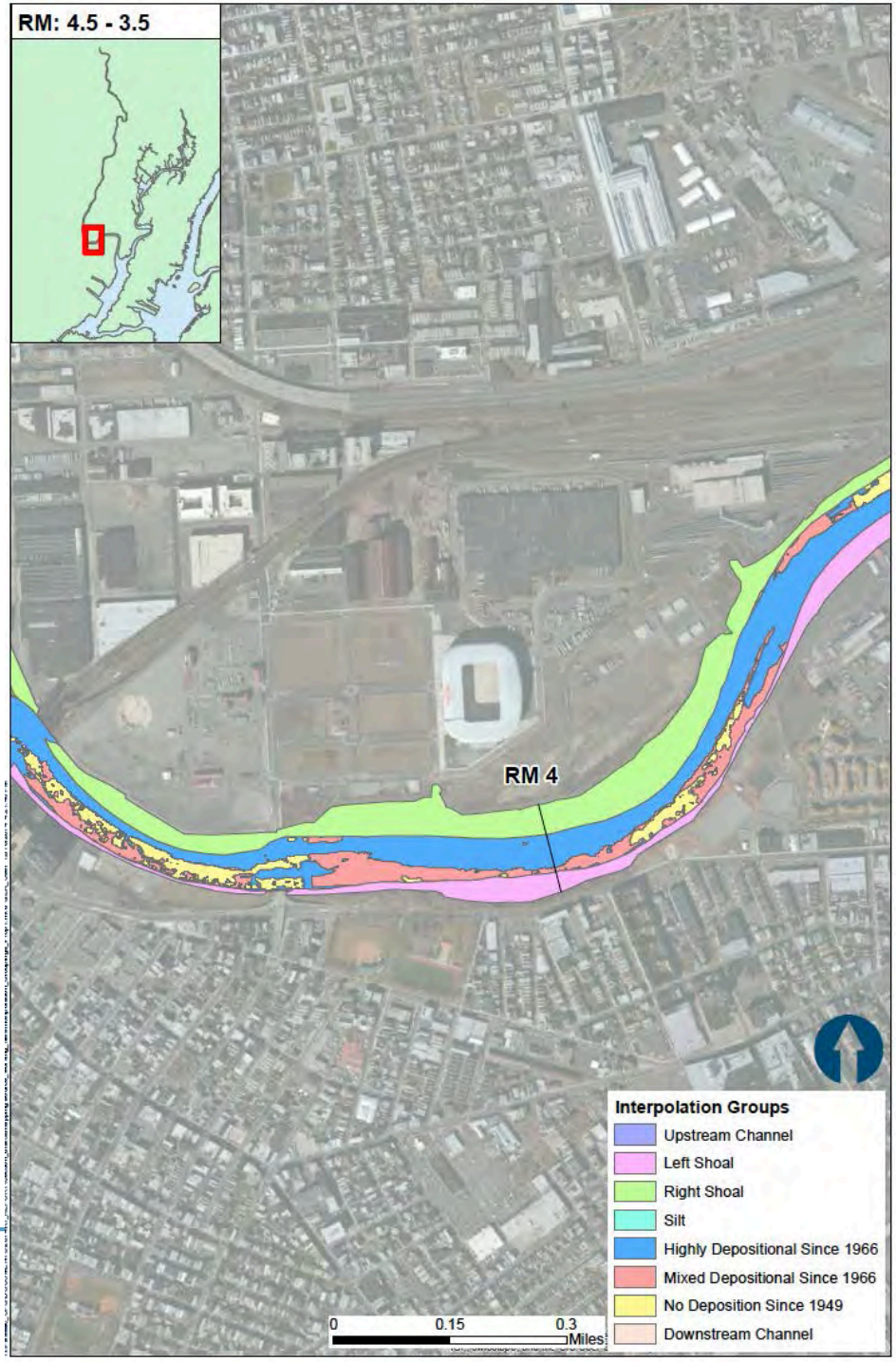

RM: 10.5 - 9
Silt 6
Silt 5
RM 10
Silt 5
Silt 4
Silt 4
RM 9
Silt 2
Silt 3
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.125
0.25
Miles

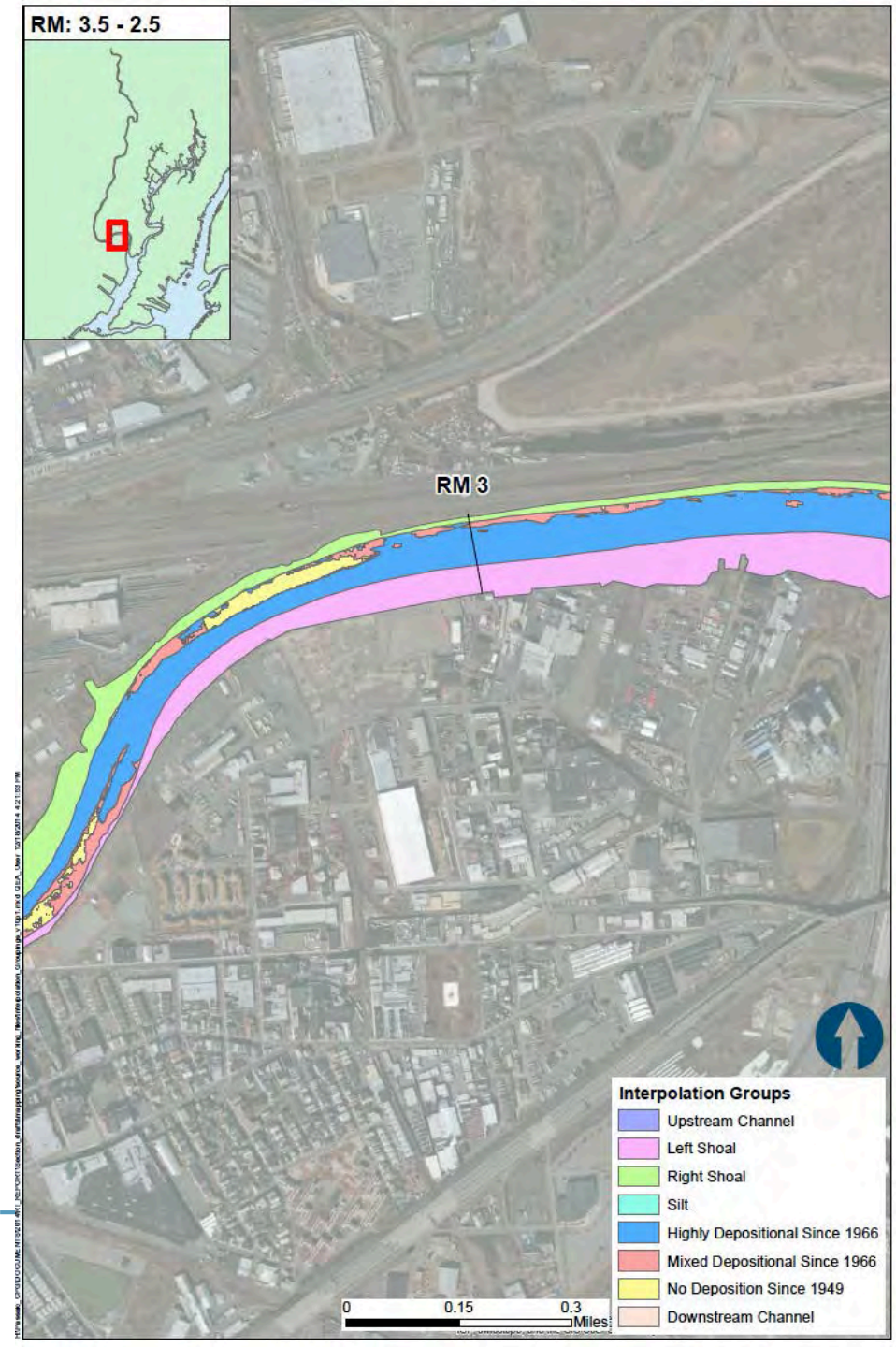

RM: 9 - 8
RM 9
Silt 4
Silt 3
Silt 2
Silt 2
RM 8
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.075
0.15
Miles

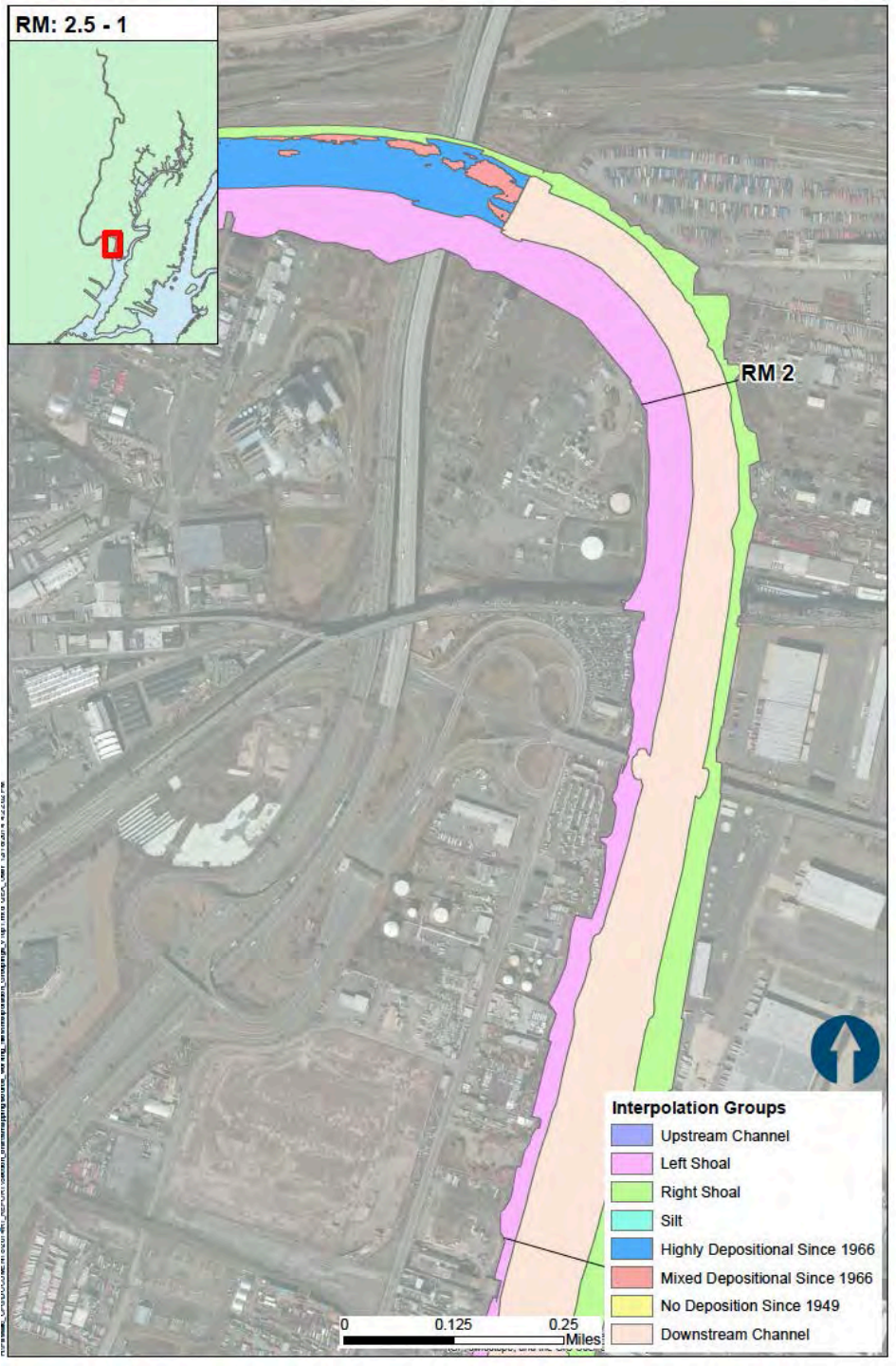

RM: 8 - 7
RM 8
Silt 1
RM 7.8
(Upstream limit of
1966 bathymetry)
RM 7
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.1
0.2
Miles


RM: 7 - 5.5
RM 7
RM 6
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.125
0.25
Miles


RM: 5.5 - 4.5
RM 5
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.1
0.2
Miles


RM: 4.5 - 3.5
RM 4
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.15
0.3
Miles


RM: 3.5 - 2.5
RM 3
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.15
0.3
Miles


RM: 2.5 - 1
RM 2
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.125
0.25
Miles

Sampling Density

Sample Count for Surface Sediments

	RM 0 – RM 8	RM 8 – RM 14	RM 14 – RM 17.6
Shoal	114	50	5
Non-dep channel	4		
Mixed dep channel	24		
High dep channel	32		
Silt deposits	4	64	
Channel		71	24
RM10.9 Silt Deposit		64	
Downstream Channel	24		

Samples Per Acre for 2,3,7,8-TCDD Surface Sediments

	RM 0 – RM 8	RM 8 – RM 14	RM 14 – RM 17.6
Shoal	0.30	0.88	0.52
Non-dep channel	0.21		
Mixed dep channel	0.48		
High dep channel	0.29		
Silt deposits	1.39	1.60	
Channel		0.60	0.23
RM10.9 Silt Deposit		4.94	
Downstream Channel	0.22		

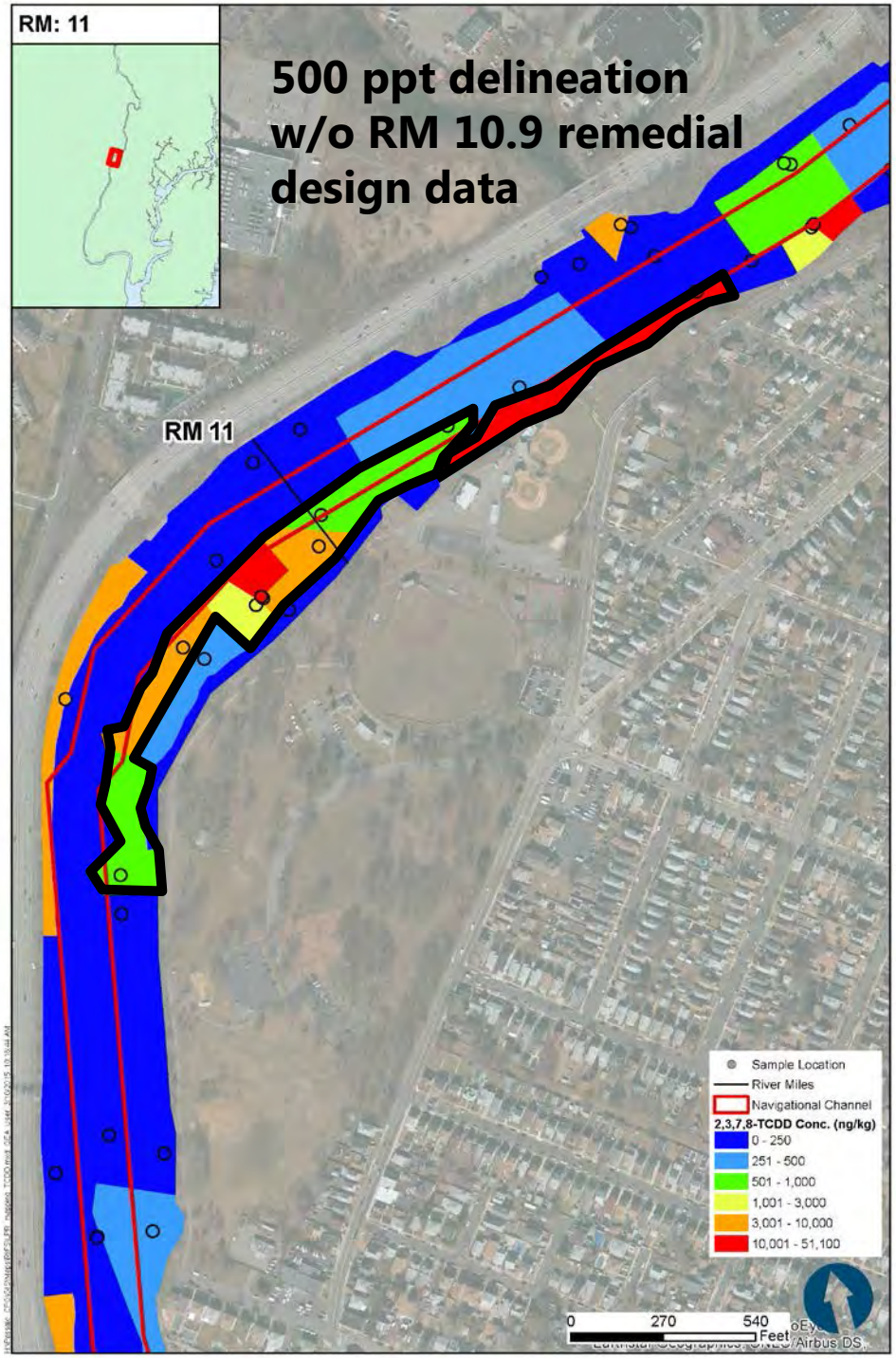
Uncertainty

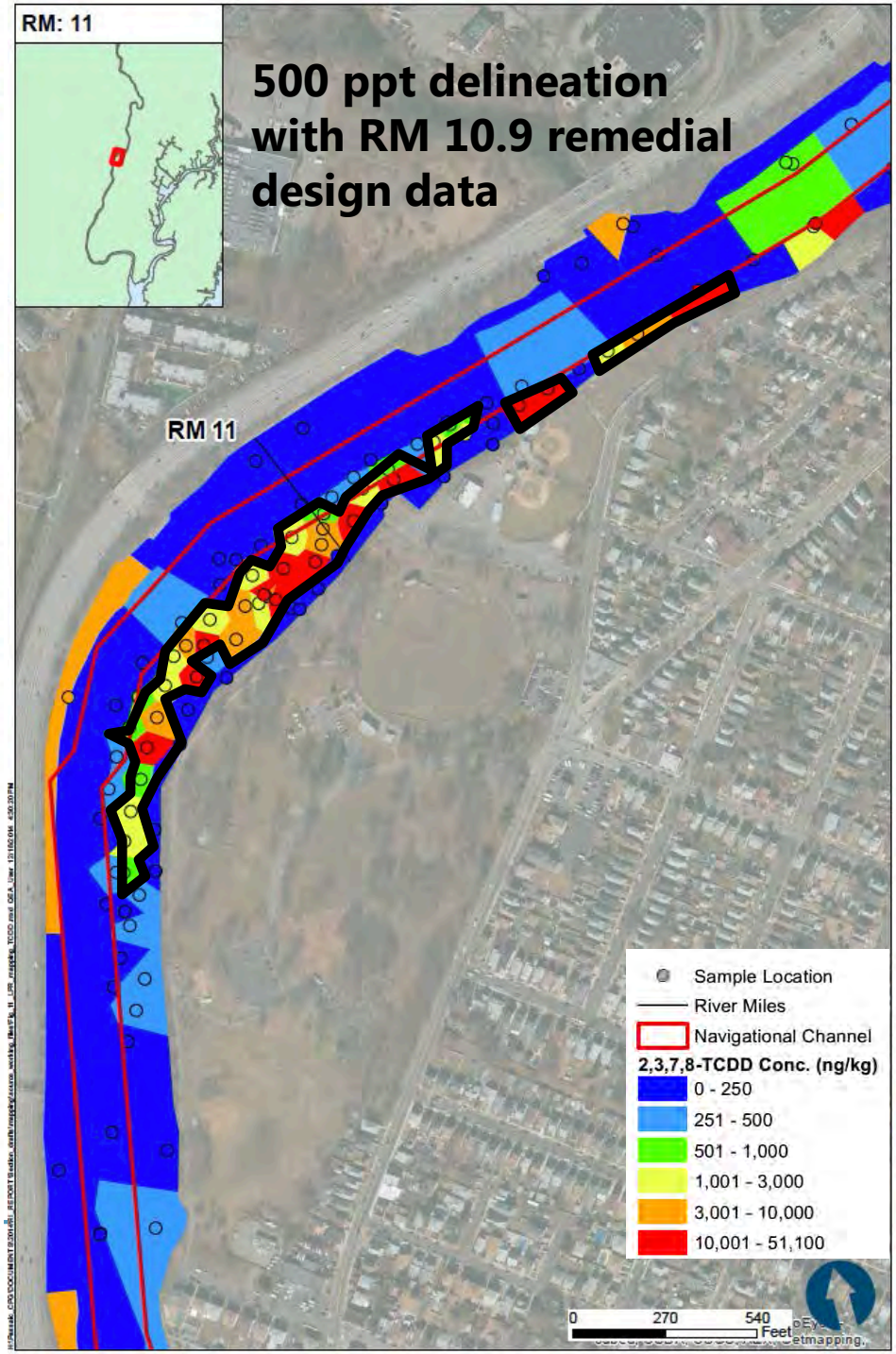
Major Sources of Uncertainty

- Sparseness of the sampling locations
- Short-scale spatial variability ("noise")
- The factors that drive concentration are only approximately known
  - Erosion/deposition history
  - Sediment grain size and organic carbon content
  - Location of original sources

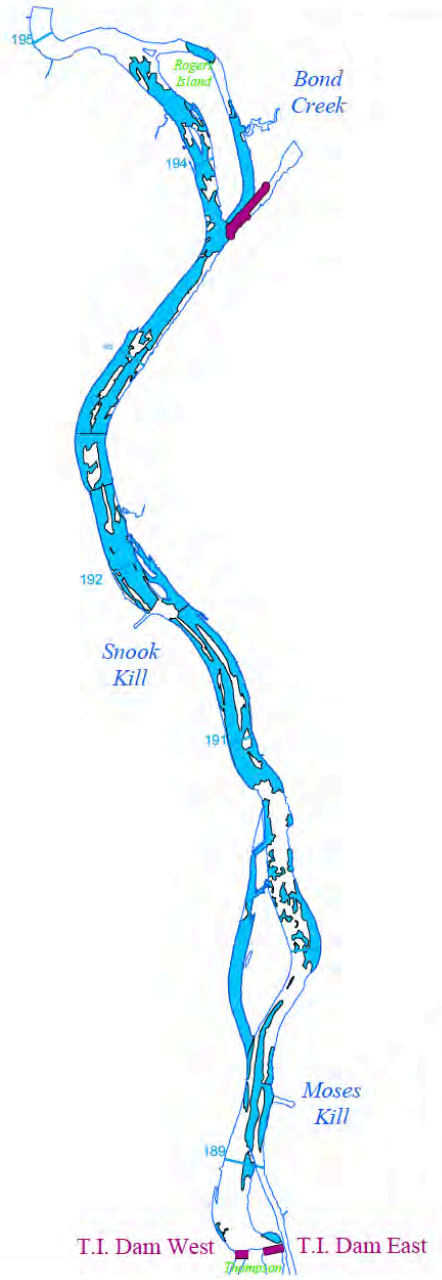
Implications of Uncertainty

- Correlation among measured concentrations complicated by variability in factors driving concentration and imprecision of the partitioning of the river
- Any interpolation approach yields an approximate mapping of concentrations
  - Sufficient to identify regions of higher and lower concentrations
  - Sufficient for the relative evaluation of remedial alternatives

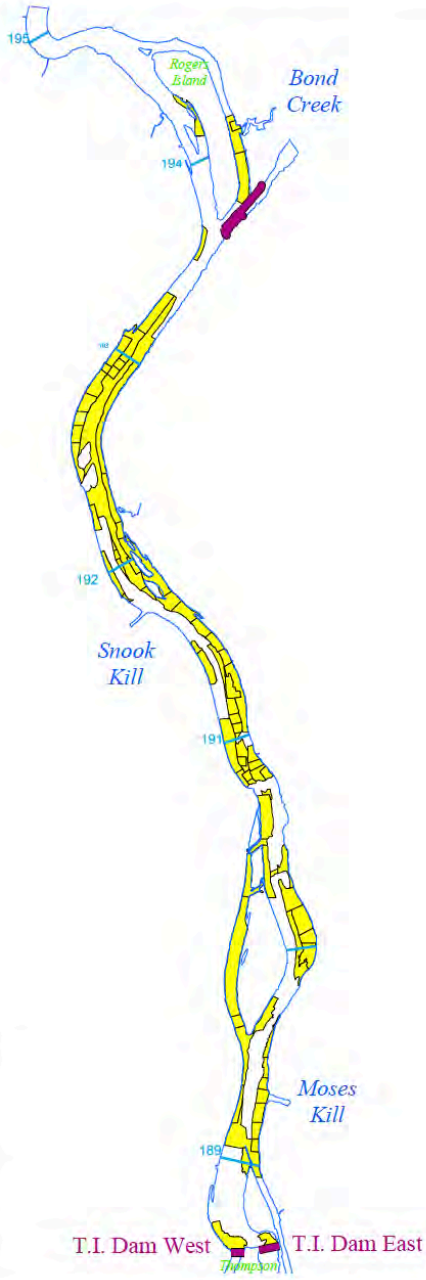

RM: 11
500 ppt delineation w/o RM 10.9 remedial design data
RM 11
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
270
540
Feet
Airbus DS


RM: 11
500 ppt delineation with RM 10.9 remedial design data
RM 11
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
270
540
Feet

GE Phase 1 and Phase 2 Delineation



EPA REM/3/10/Select Delineation



Total Delineated Area River Section 1 (acres)	
GE Phase 1 and Phase 2	EPA REM/3/10/ Select
311	266 (15)

LOCATOR MAP OF THE UPPER HUDSON RIVER

GRAPHIC SCALE

0 2,700 5,400 Feet

LEGEND

GE Phase 1 and 2

- Dredge Area Delineation
- Isolated Dredge Area

EPA REM 3/10/Select

- Dredge Area Delineation
- Shoreline
- River Miles
- Dams and Locks

Based on the 3/8/06 GIS database file

General Electric Company
Hudson River Project

Comparison of GE and EPA Delineations

River Section 1

QEA Quantitative Environmental Analysis, LLC

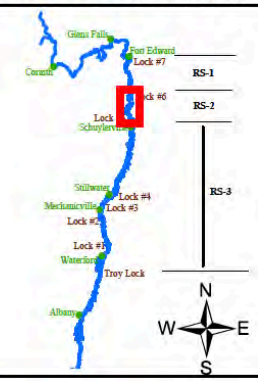
GENdad:133 March 2006

GE Phase 1 and Phase 2 Delineation

EPA REM/3/10/Select Delineation

Total Delineated Area River Section 2 (acres)	
GE Phase 1 and Phase 2	EPA REM/3/10/ Select
72	74 (2)

LOCATOR MAP OF THE UPPER HUDSON RIVER



GRAPHIC SCALE

0 2,600 5,200 Feet

LEGEND

GE Phase 1 and 2

- Dredge Area Delineation
- Isolated Dredge Area

EPA REM 3/10/Select

- Dredge Area Delineation
- Shoreline
- River Miles
- Dams and Locks

Based on the 3/8/06 GIS database file

General Electric Company
Hudson River Project

Comparison of GE and EPA Delineations

River Section 2

QEA Quantitative Environmental Analysis, LLC

GENdad:133 March 2006

Changes from FS to Design for Fox River OU4

- 2003 ROD specified remediation of 1,030 acres
- Basis of Design Report that included a dense pre-design sampling set specified remediation of 1,170 acres

Mapping is Only One Source of Uncertainty

- Exposure changes resulting from remediation
  - *Concentrations in targeted areas*
  - *Concentrations outside targeted areas*
  - Post-remedy residuals
  - Effectiveness of capping
  - Recontamination from unremediated areas, dredging releases and boundaries
- Limitations of the models
  - Coarse spatial scale relative to concentration patterns and erosion/deposition behavior
  - Model error
- Imprecise assumptions about exposure, future conditions and the progress of remediation

Dealing With Mapping Uncertainty

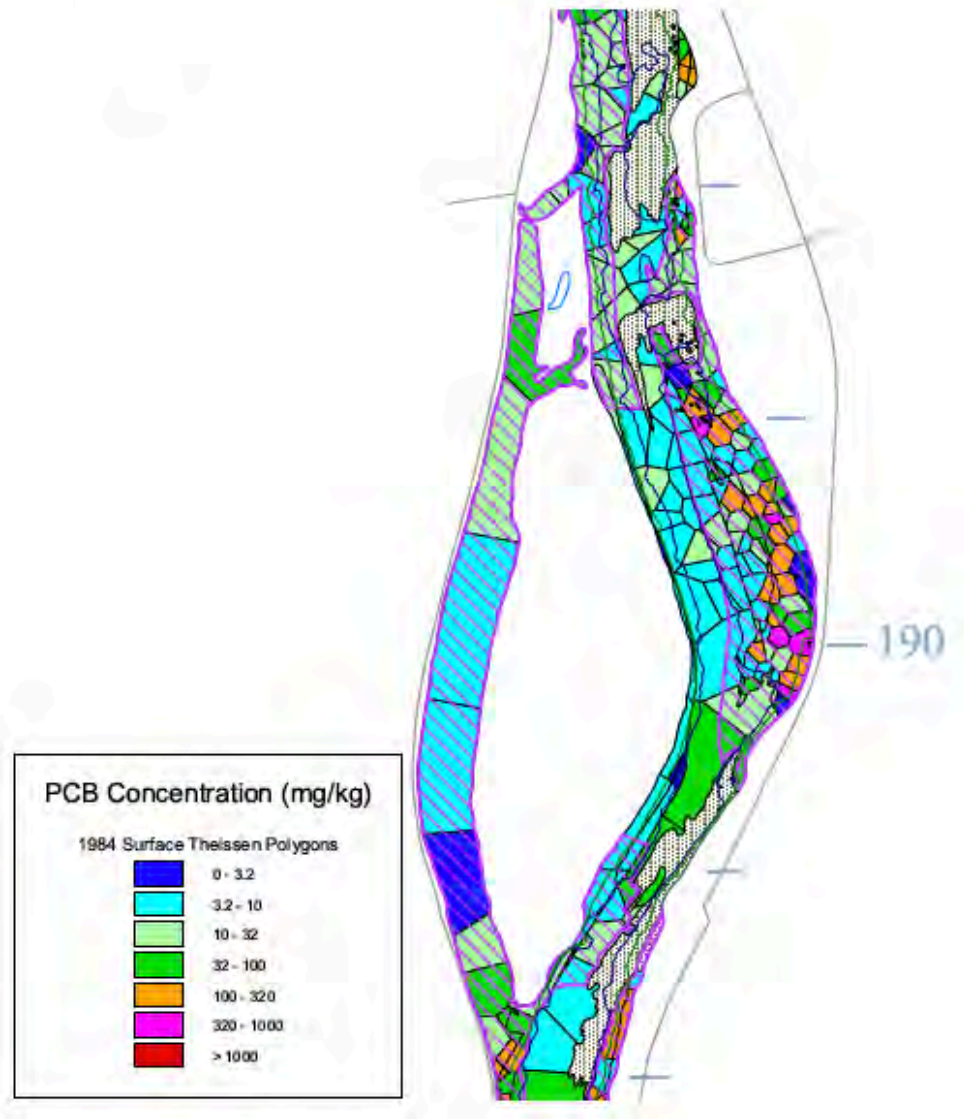
- Intensive pre-design sampling improves concentration estimates, but the other sources of uncertainty remain
- The uncertainty of remedy effectiveness is a reason for Adaptive Management
- Accounting for mapping uncertainty in the FS will not materially increase the understanding of true remedy effectiveness
  - All we really know is that the final determination of the area above a RAL will yield a result that is more or less than was specified in the FS, but experience indicates it will not be radically different

Interpolating Within the Partitioned River Done Using Thiessen Polygons

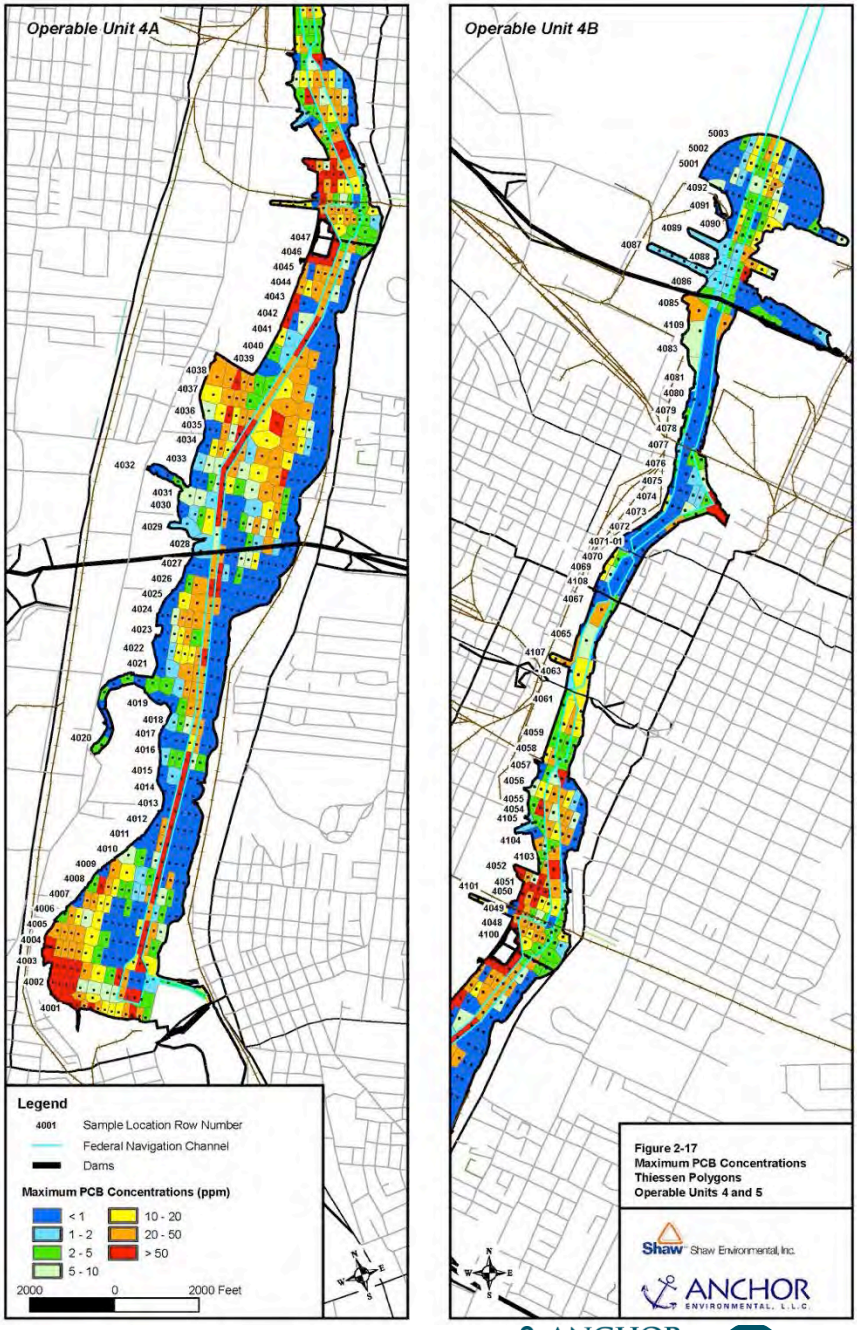
Examples of Where Thiessen Polygons Were Used to Map Contamination

- Hudson River
- Fox River
- Lower Duwamish Waterway
- Portland Harbor
- Grasse River
- Onondaga Lake
- Buffalo River
- Housatonic River

Hudson River Feasibility Study



Fox River Basis of Design Report



Grasse River Analysis of Alternatives Report

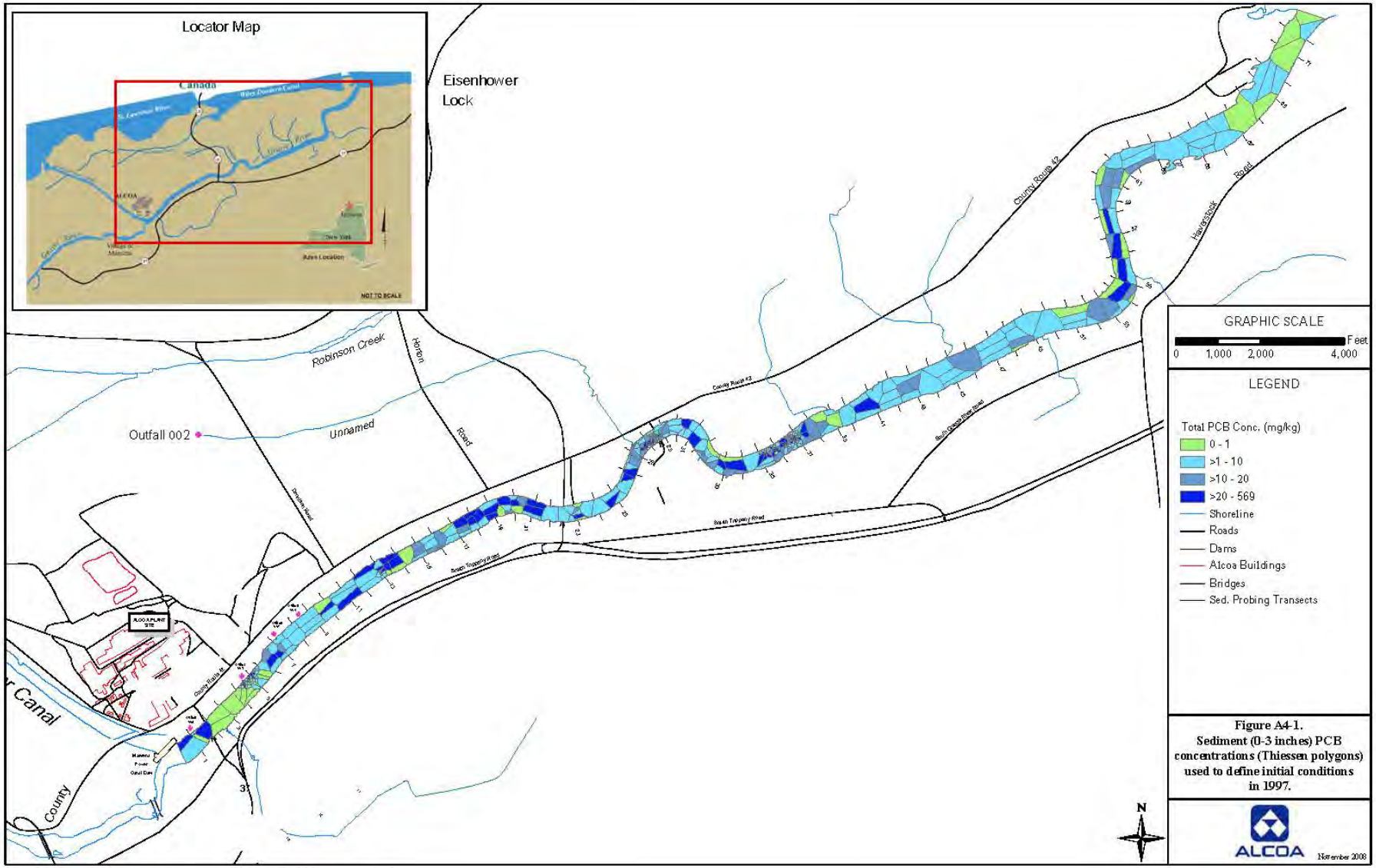
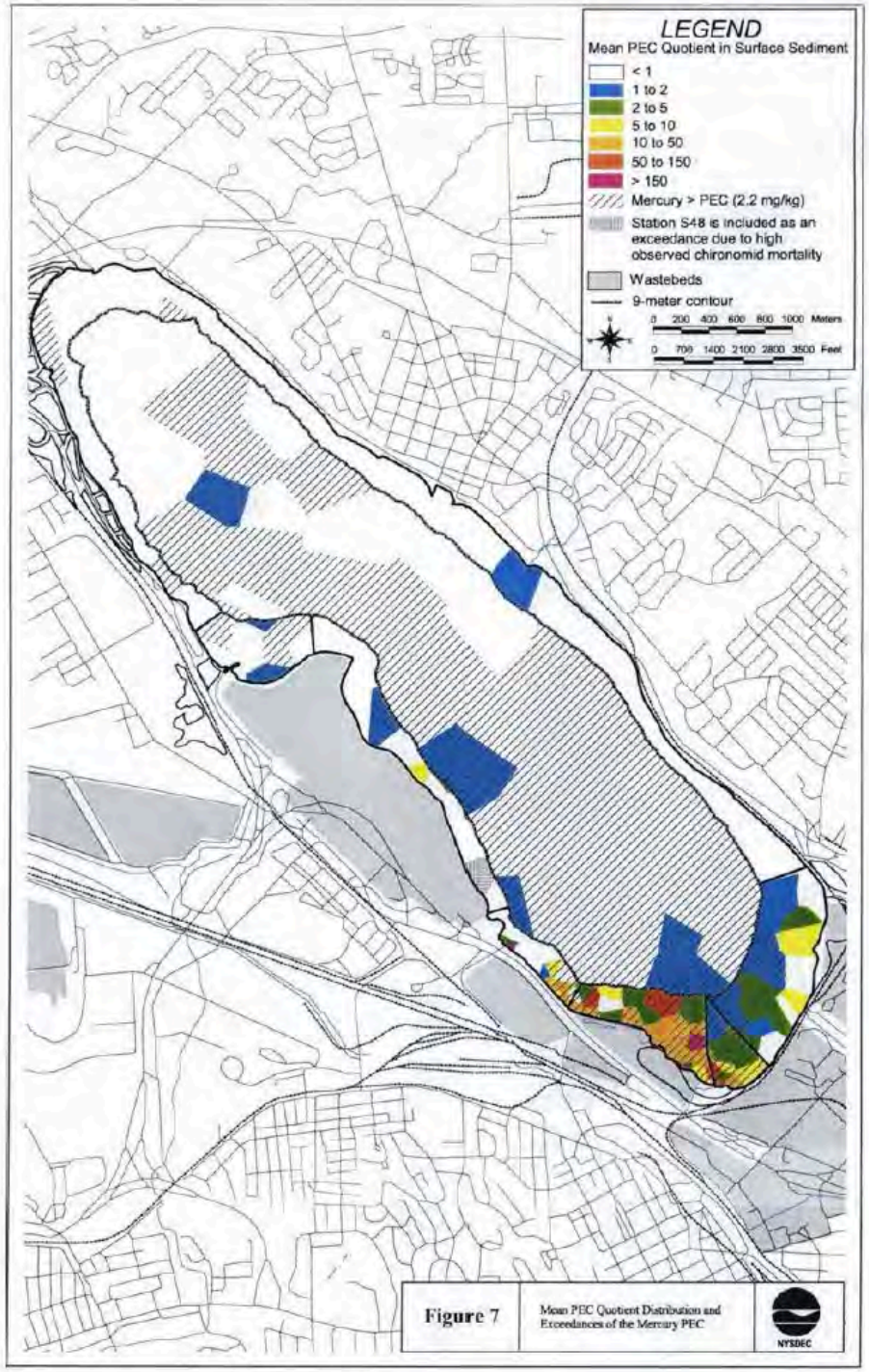


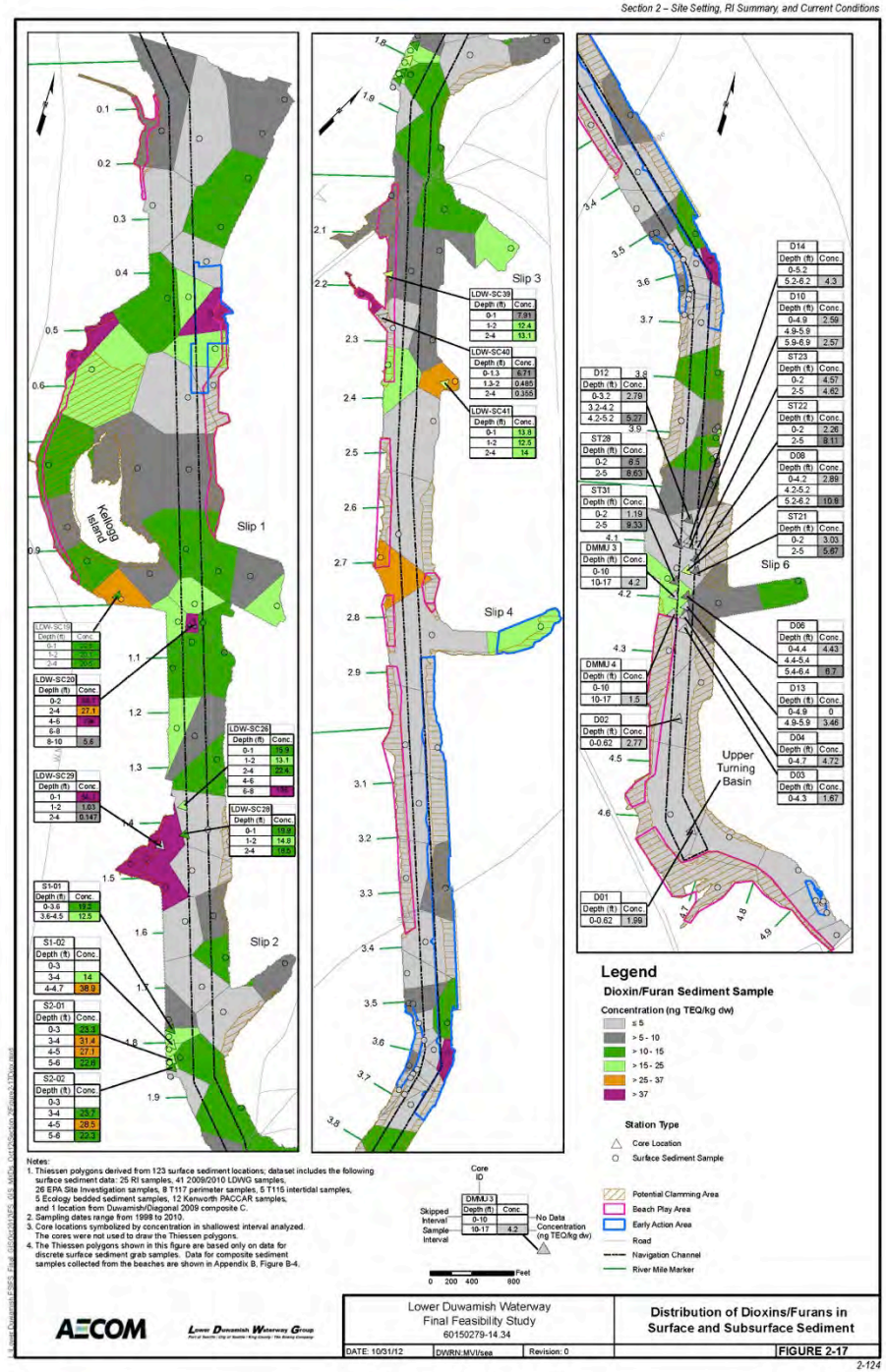
Figure A4-1.
Sediment (0-3 inches) PCB concentrations (Thiessen polygons) used to define initial conditions in 1997.

Onondaga Lake ROD



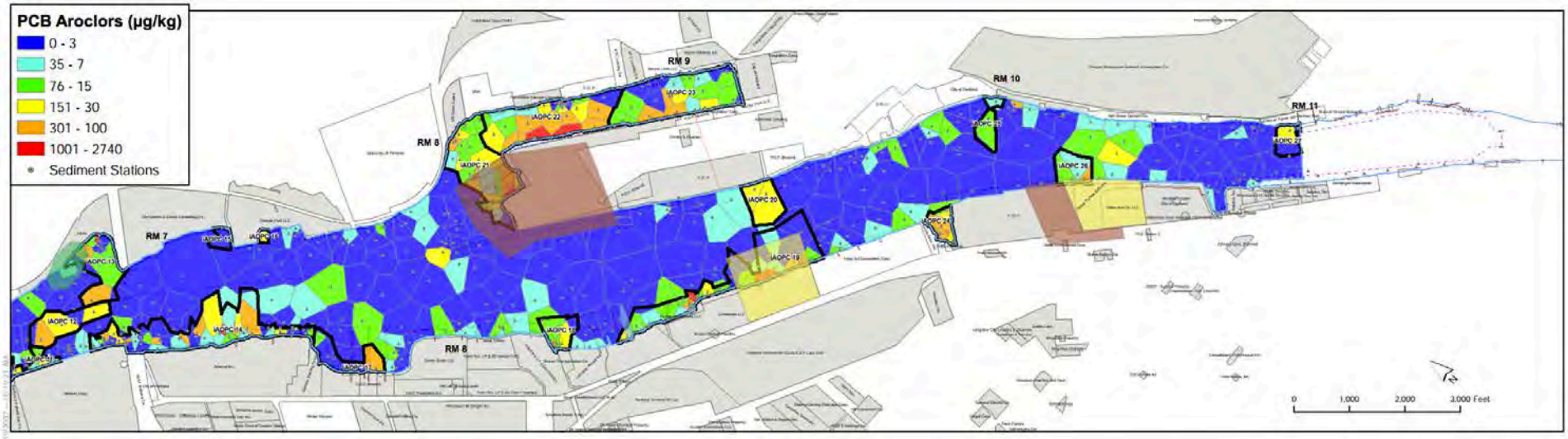
Lower Duwamish Waterway Feasibility Study

IDW used for other chemicals with much denser data sets

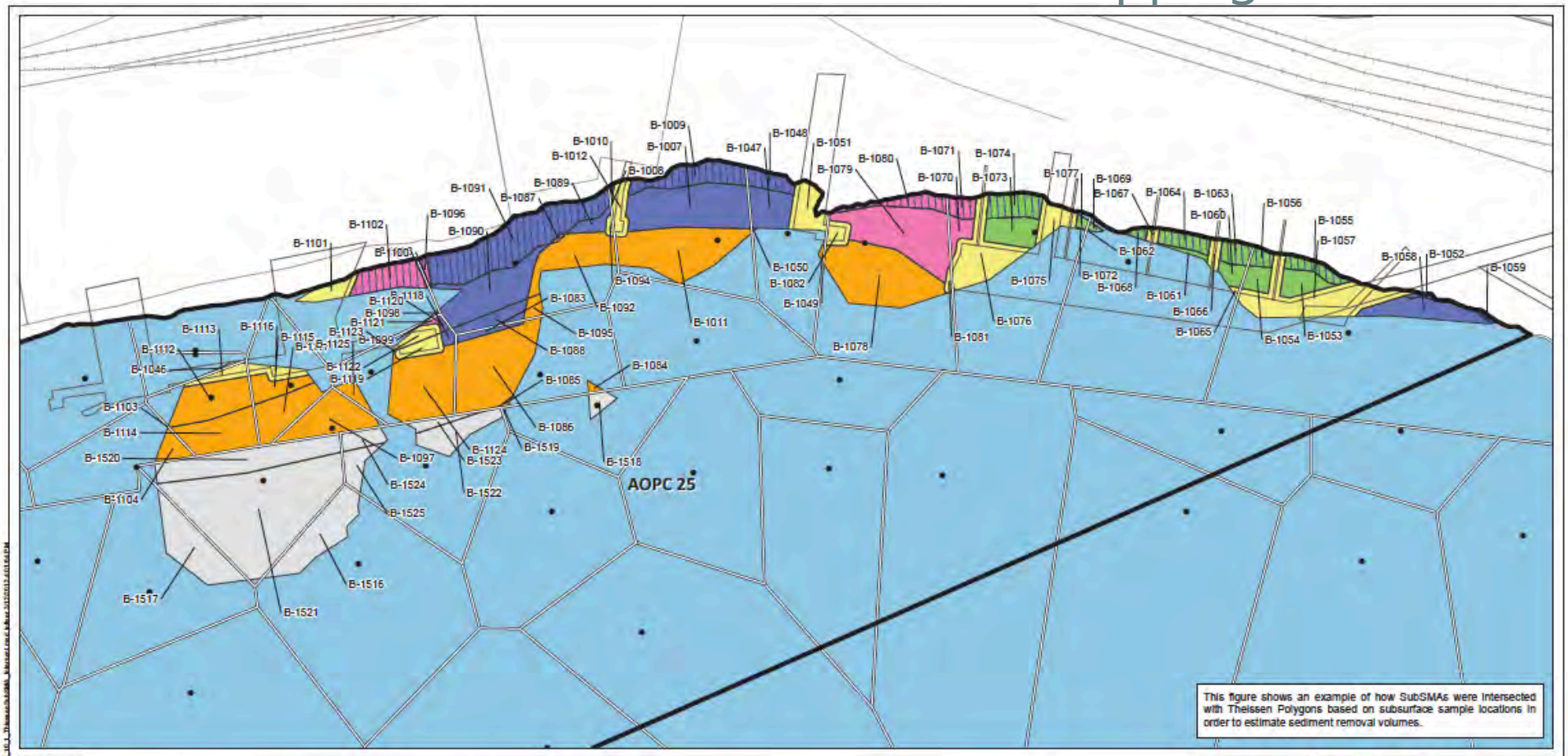


EPA-CPG Meeting 3/11/15

Portland Harbor PCB Concentration Mapping



Portland Harbor FS – Sediment Volume Mapping



ANCHOR QEA

LWG Lower Willamette Group

DO NOT QUOTE OR CITE
This document is currently under review by US EPA and its federal, state, and tribal partners, and is subject to change in whole or in part

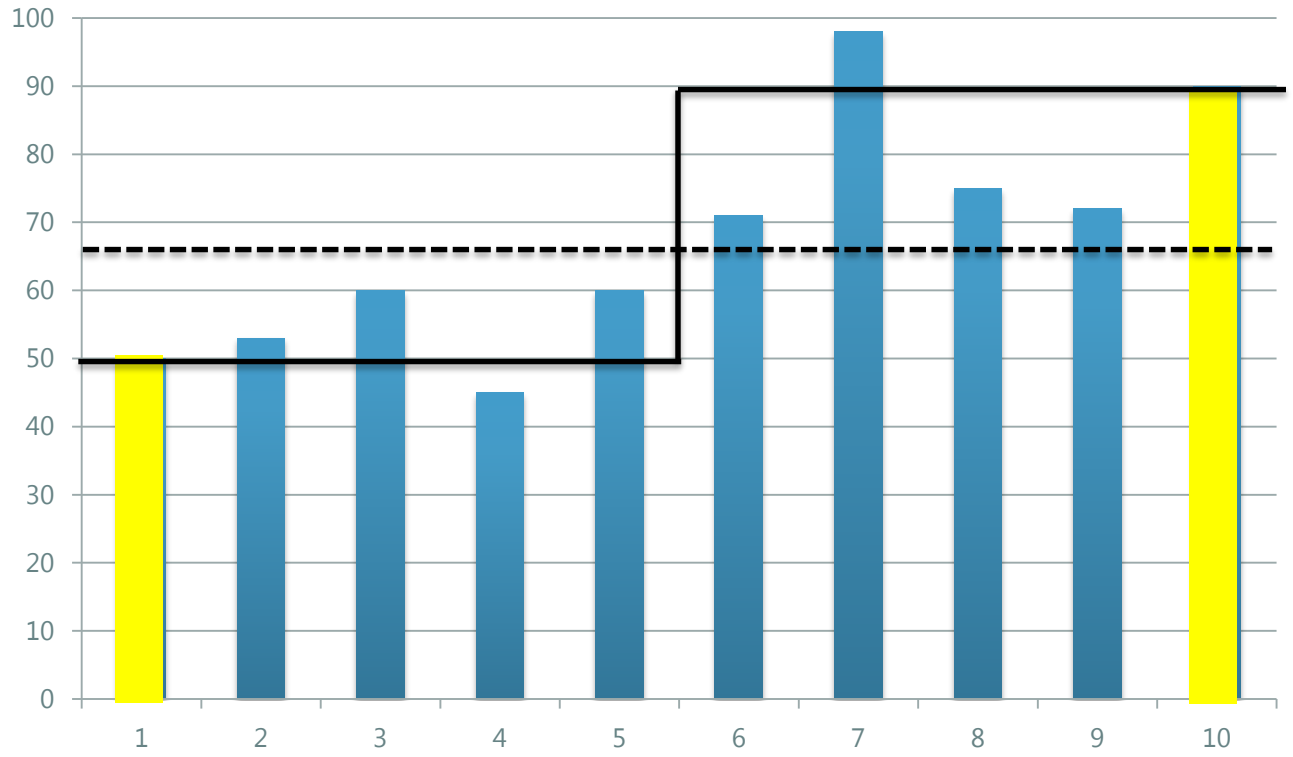
Figure 5.10-1
Portland Harbor RI/FS
Draft Feasibility Study
Example Thiessen Intersections with SubSMAs

Advantages of Thiessen Polygons

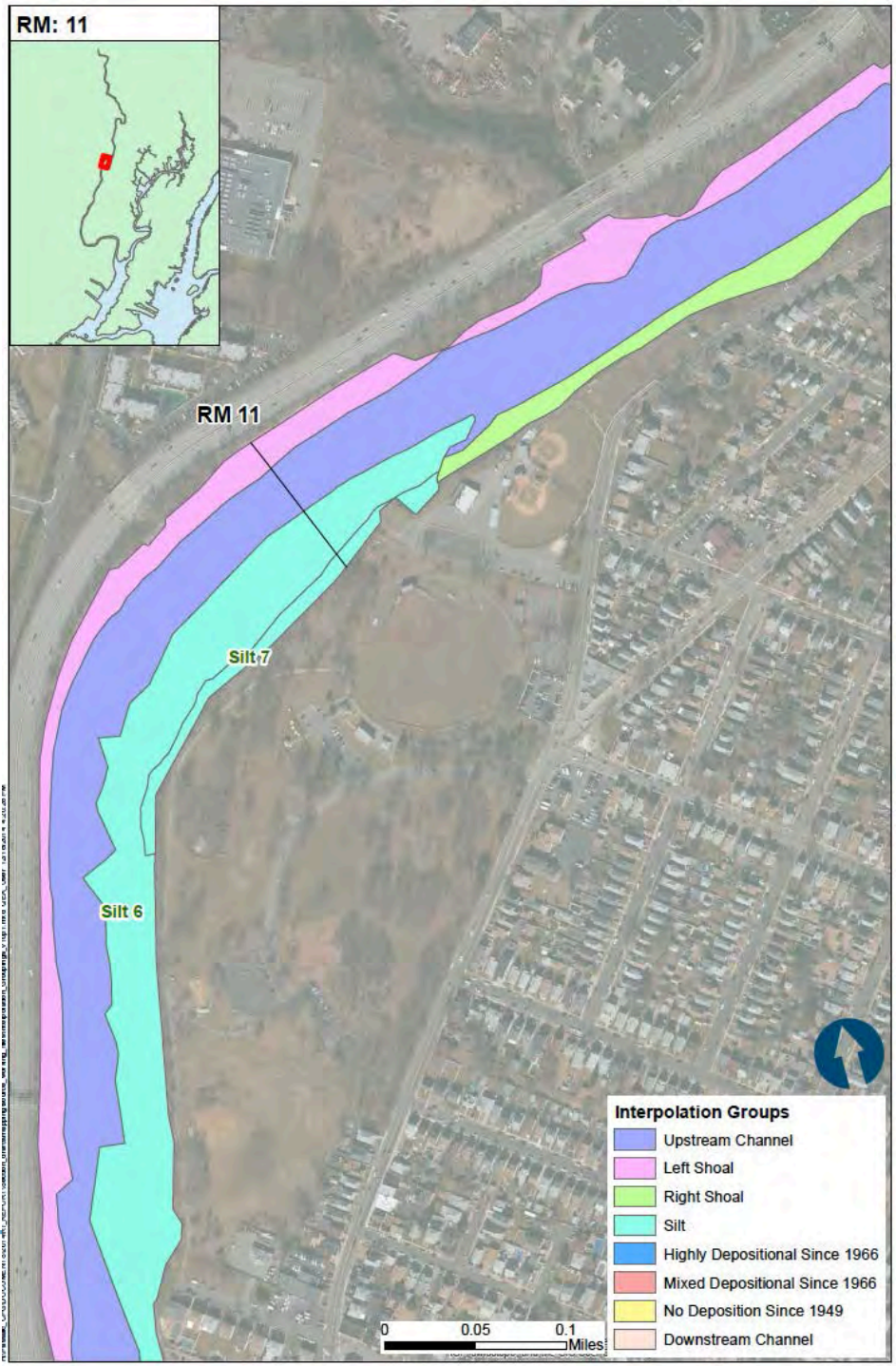
- Take account of spatial correlation, though in a limiting sense
- Reproduce the variance of the underlying data-set
  - Do not damp out the high and low parts of the concentration distribution

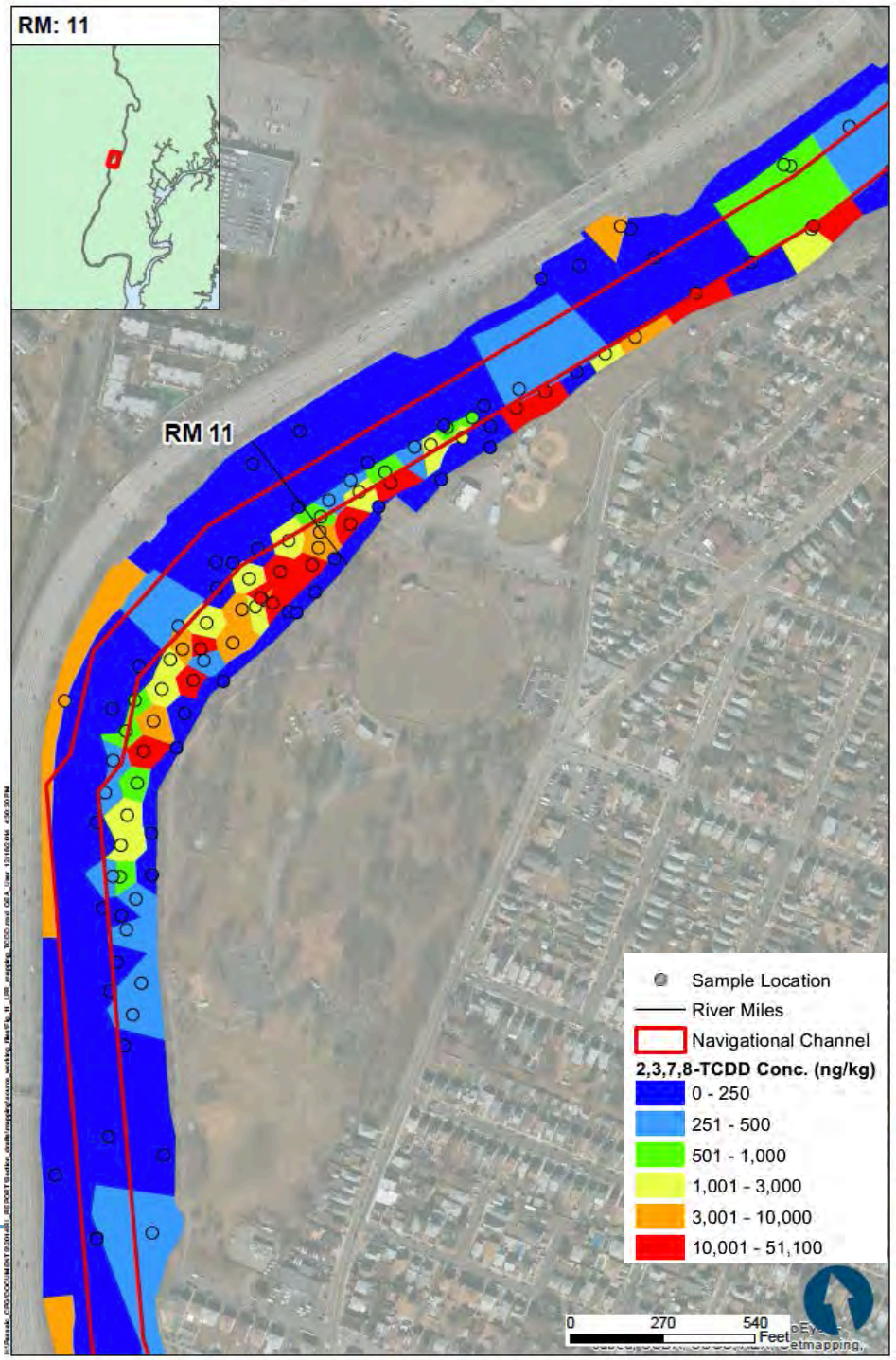
Spatial Correlation Makes Polygons More Accurate Than Broad-Scale Averaging

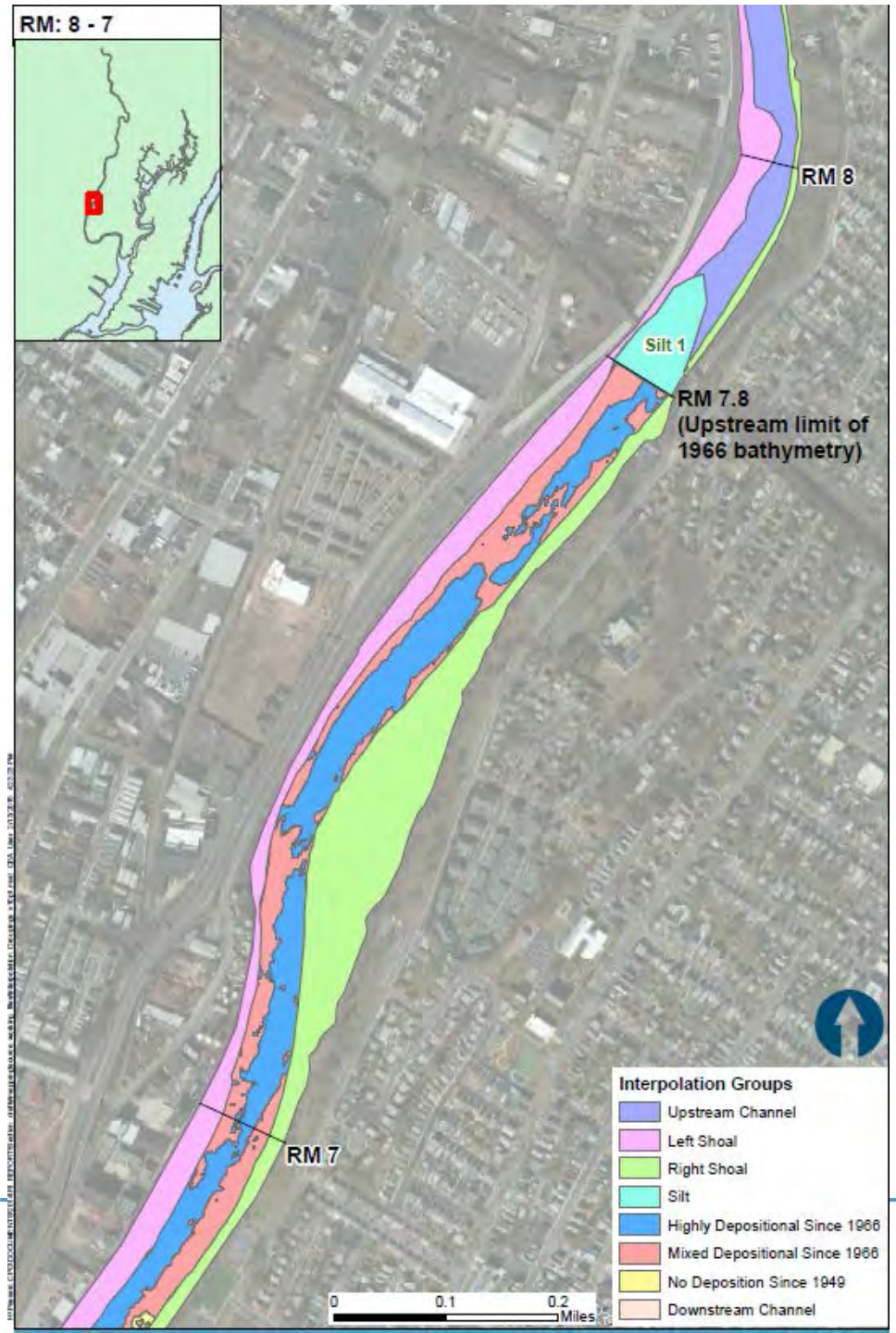
Example in which yellow locations are measured and used to interpolate between them with polygons or averaging

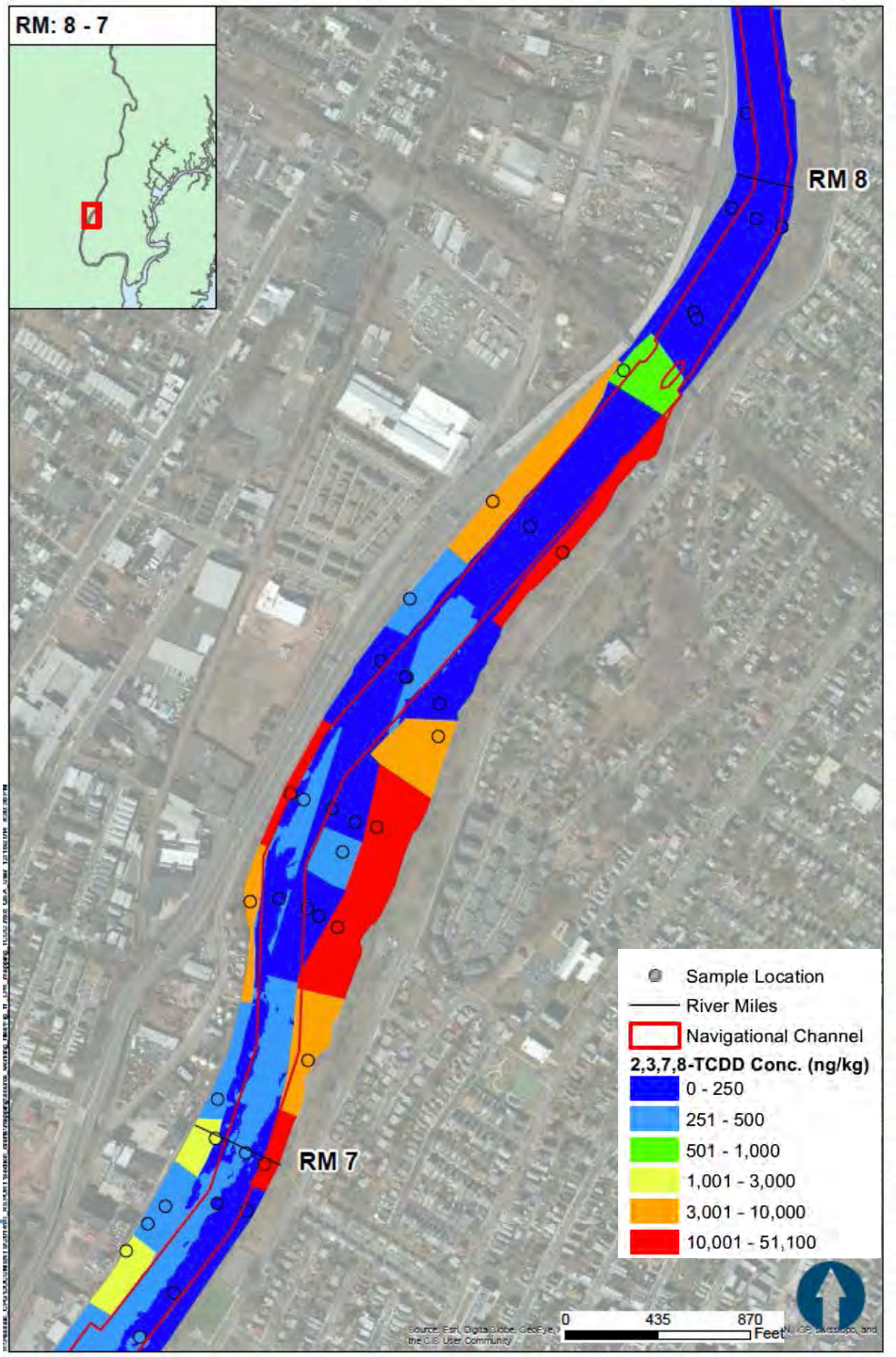


Mapping Results

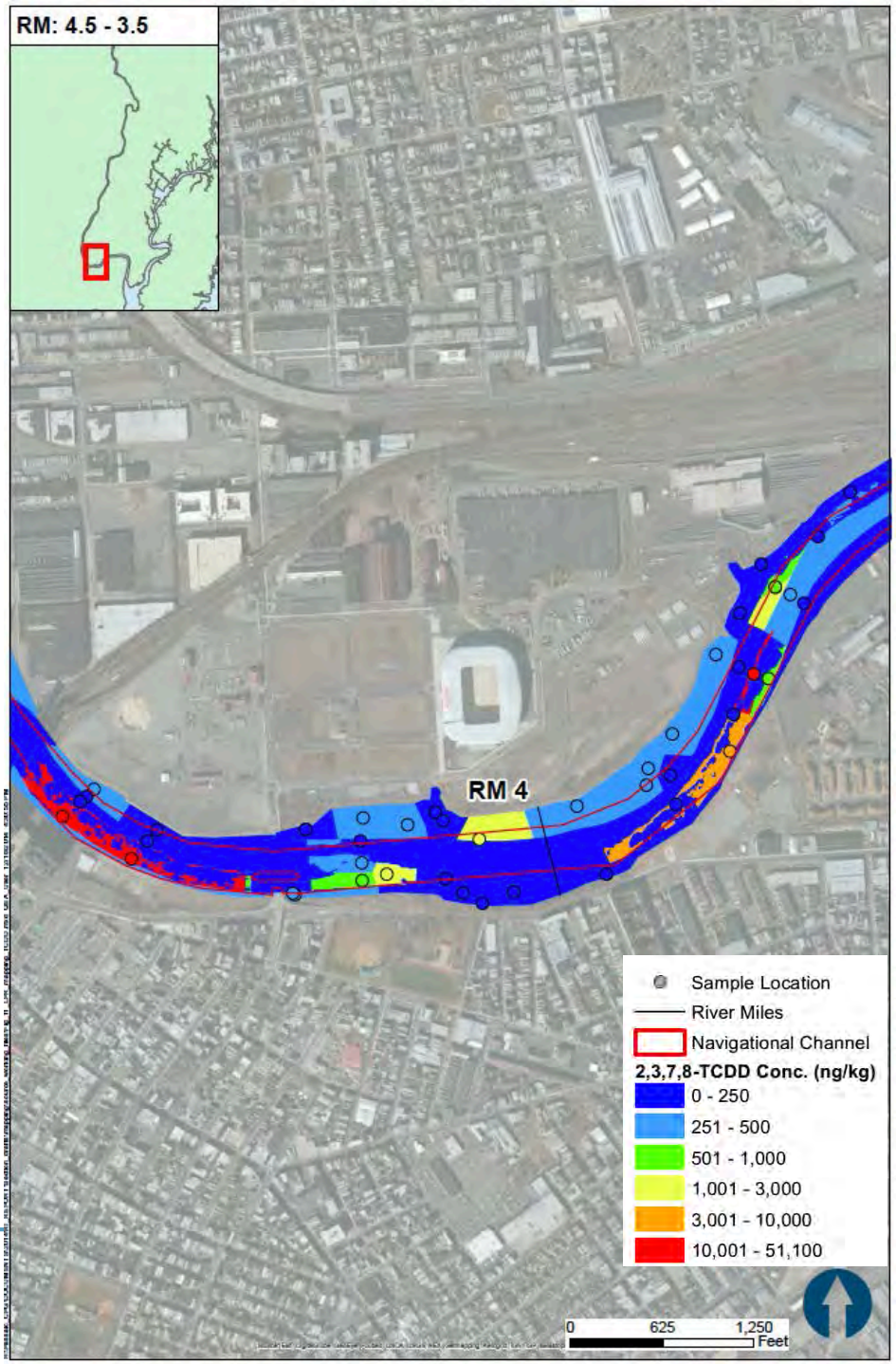

RM: 11
RM 11
Silt 7
Silt 6
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.05
0.1
Miles


RM: 11
RM 11
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
270
540
Feet

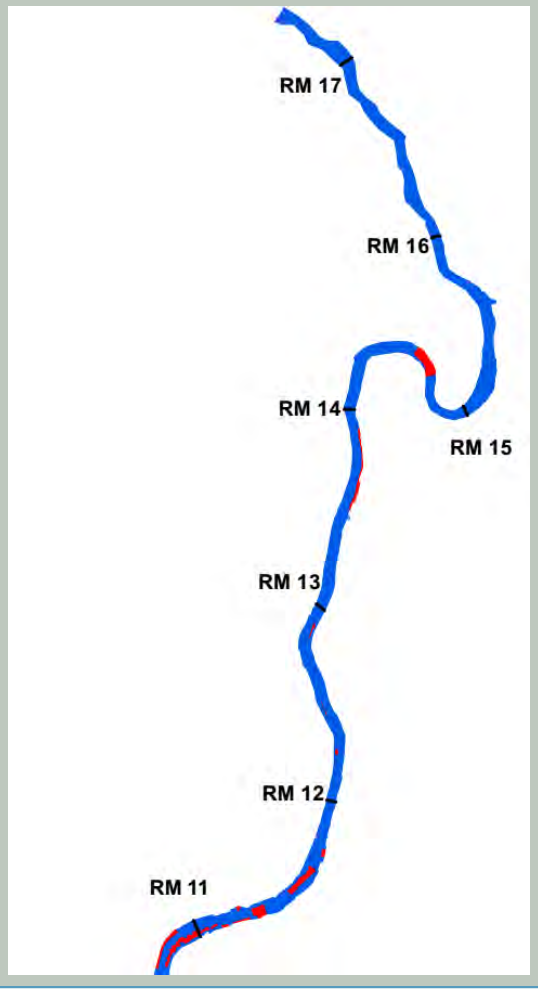

RM: 8 - 7
RM 8
Silt 1
RM 7.8
(Upstream limit of
1966 bathymetry)
RM 7
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.1
0.2
Miles

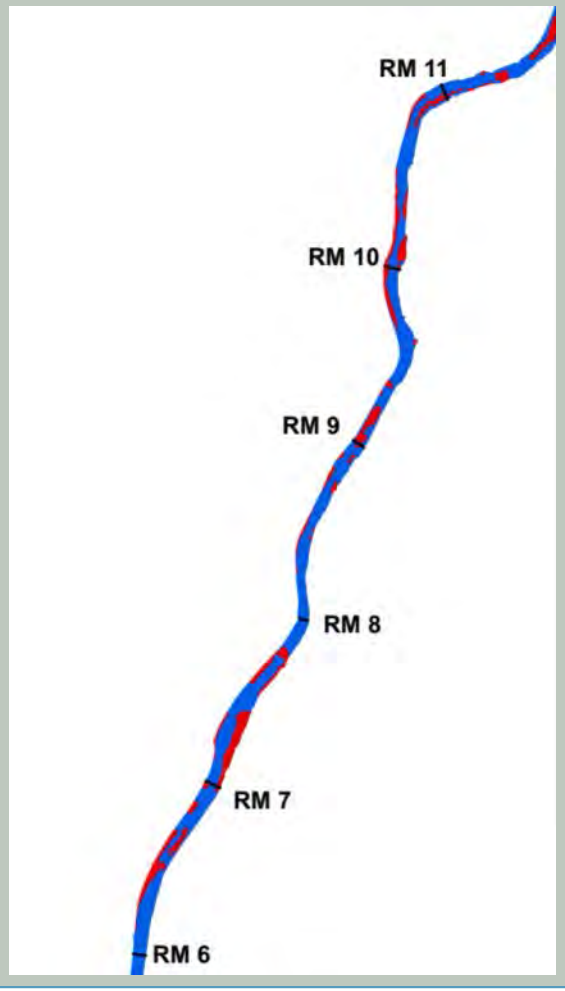

RM: 8 - 7
RM 8
RM 7
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
435
870
Feet

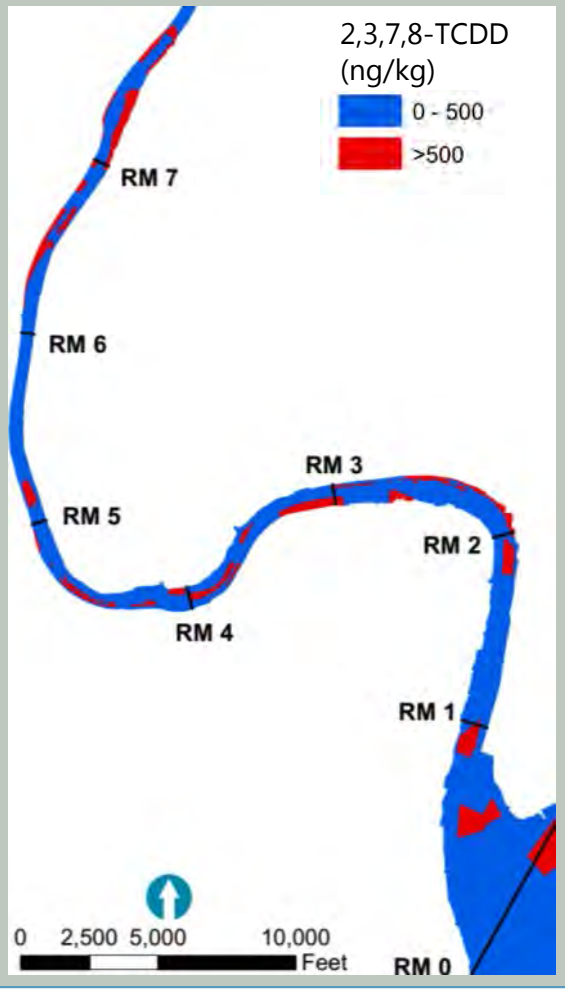

RM: 4.5 - 3.5
RM 4
Interpolation Groups
Upstream Channel
Left Shoal
Right Shoal
Silt
Highly Depositional Since 1966
Mixed Depositional Since 1966
No Deposition Since 1949
Downstream Channel
0
0.15
0.3
Miles


RM: 4.5 - 3.5
RM 4
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
625
1,250
Feet

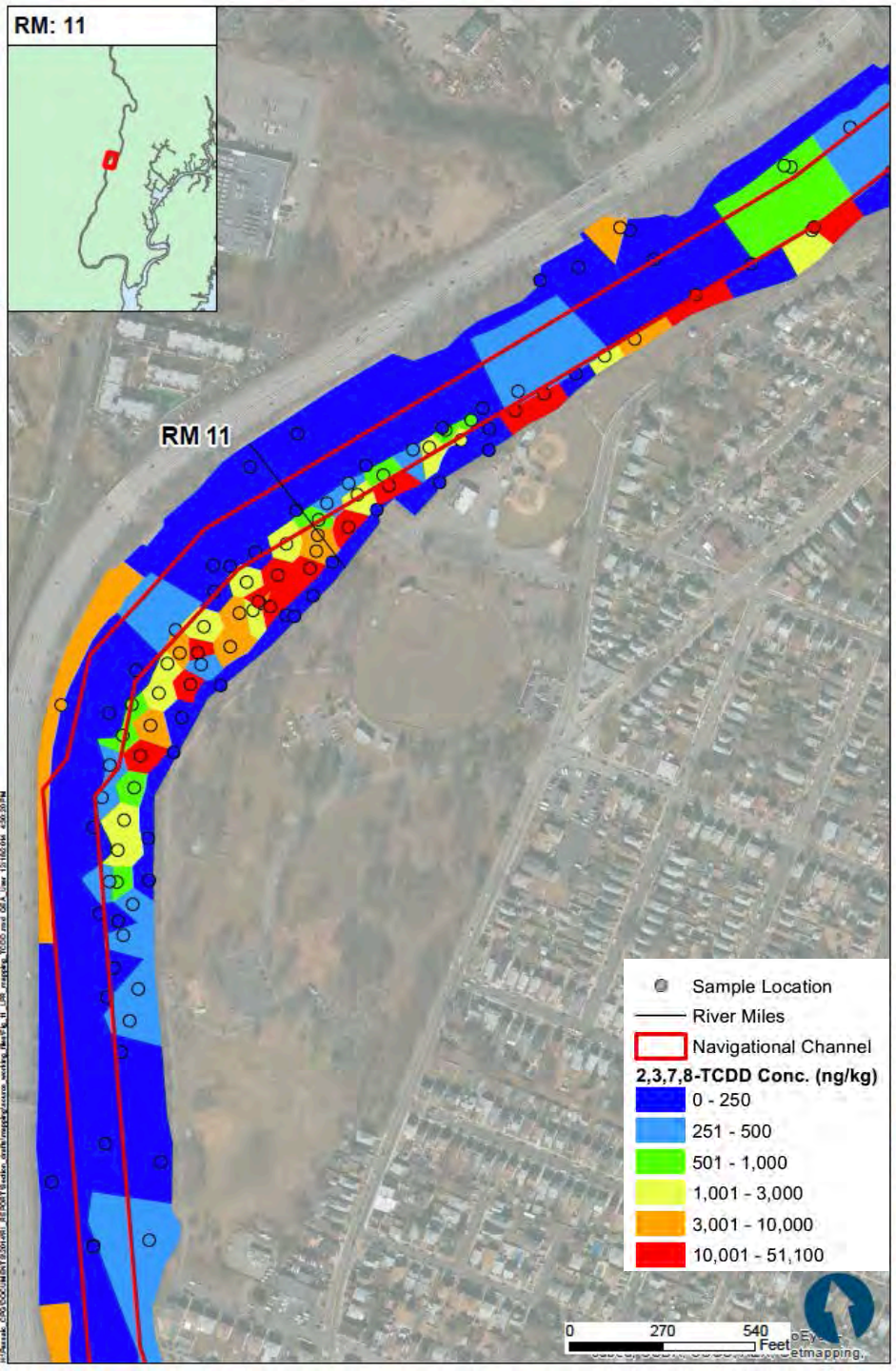
Higher 2,3,7,8-TCDD Concentrations in Discrete Pockets

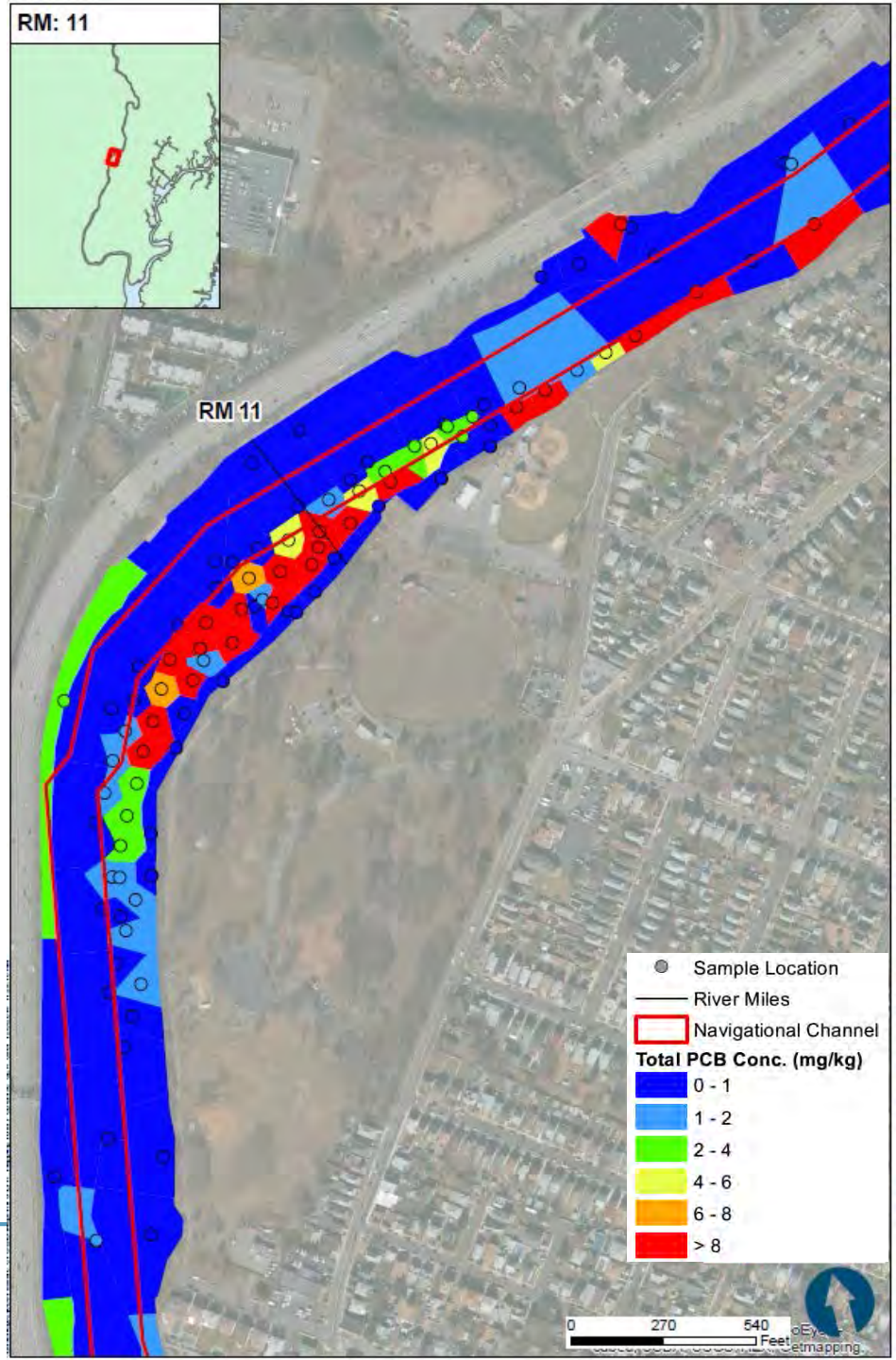


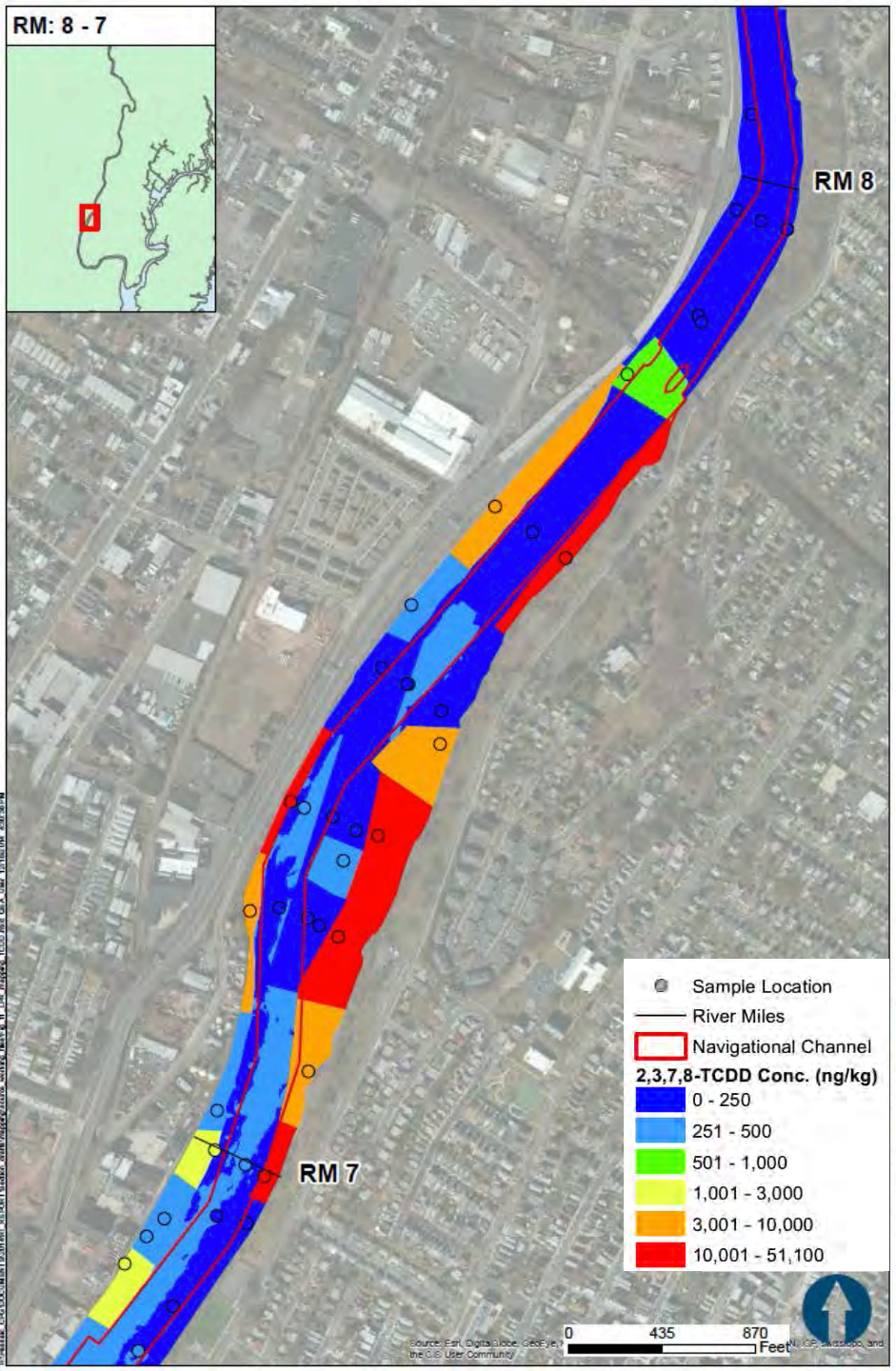


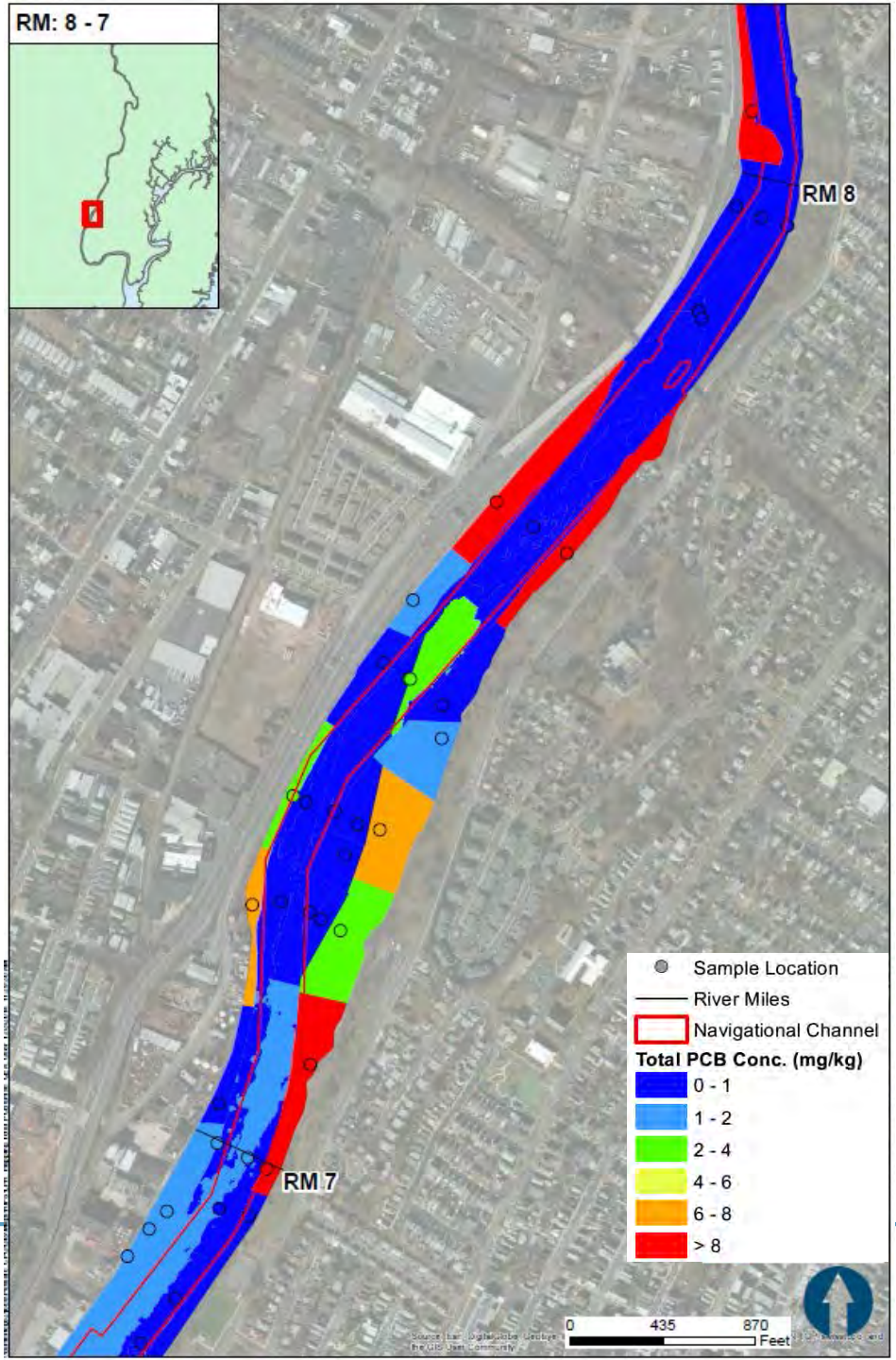


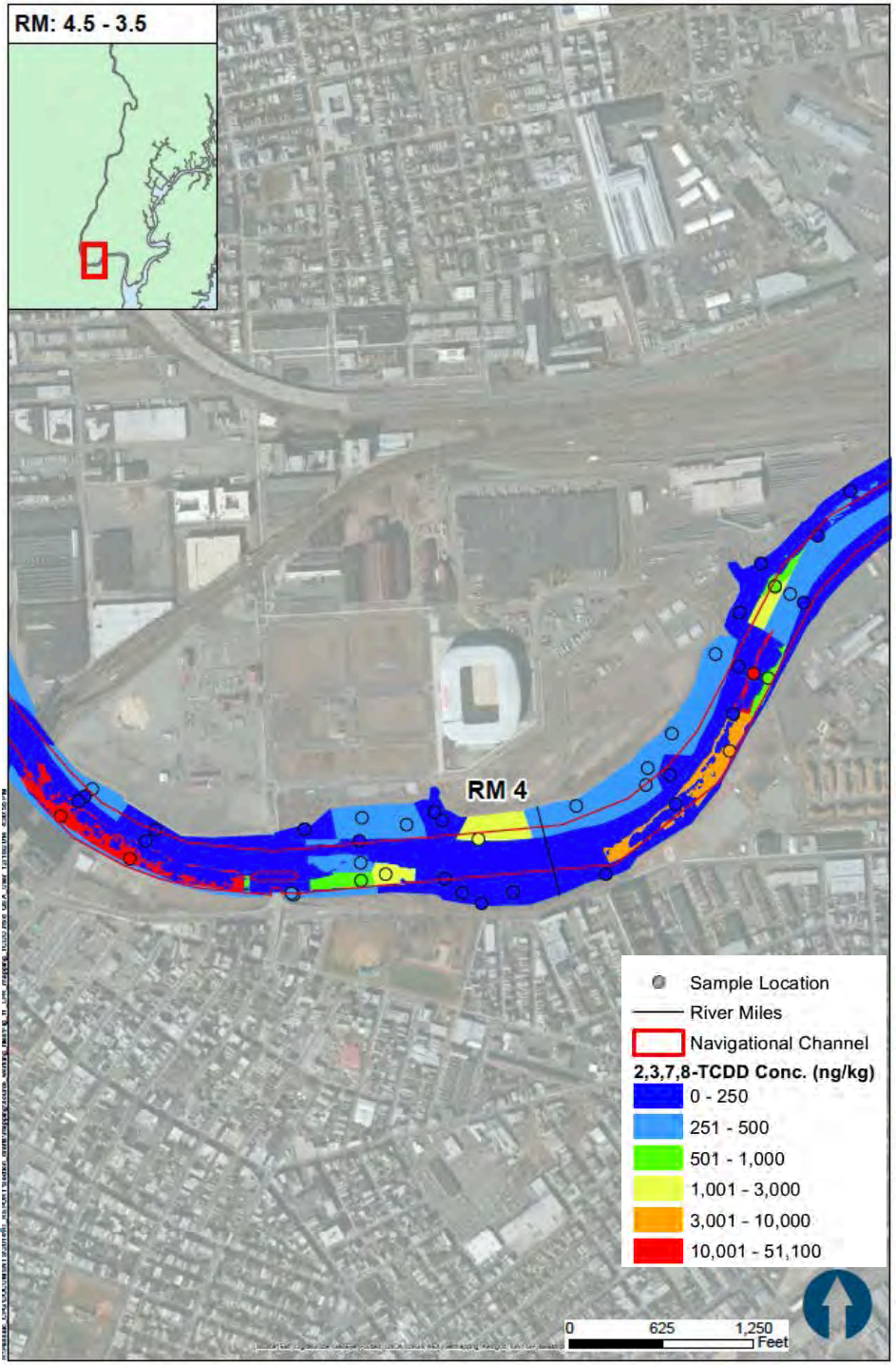
Comparison of 2,3,7,8-TCDD and PCB Mapping

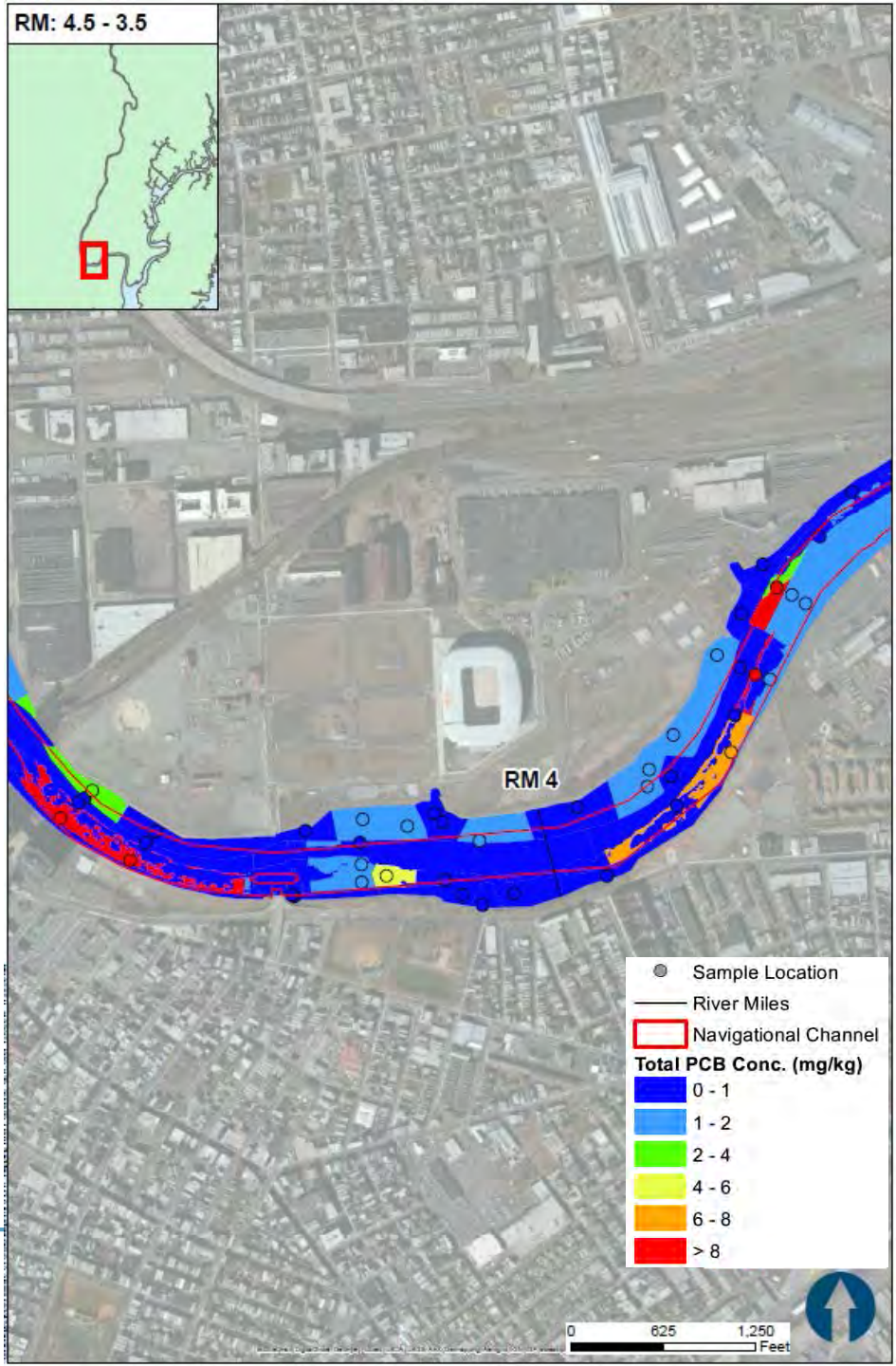

RM: 11
RM 11
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
270
540
Feet


RM: 11
RM 11
Sample Location
River Miles
Navigational Channel
Total PCB Conc. (mg/kg)
0 - 1
1 - 2
2 - 4
4 - 6
6 - 8
> 8
0
270
540
Feet


RM: 8 - 7
RM 8
RM 7
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
435
870
Feet


RM: 8 - 7
RM 8
RM 7
Sample Location
River Miles
Navigational Channel
Total PCB Conc. (mg/kg)
0 - 1
1 - 2
2 - 4
4 - 6
6 - 8
> 8
0
435
870
Feet

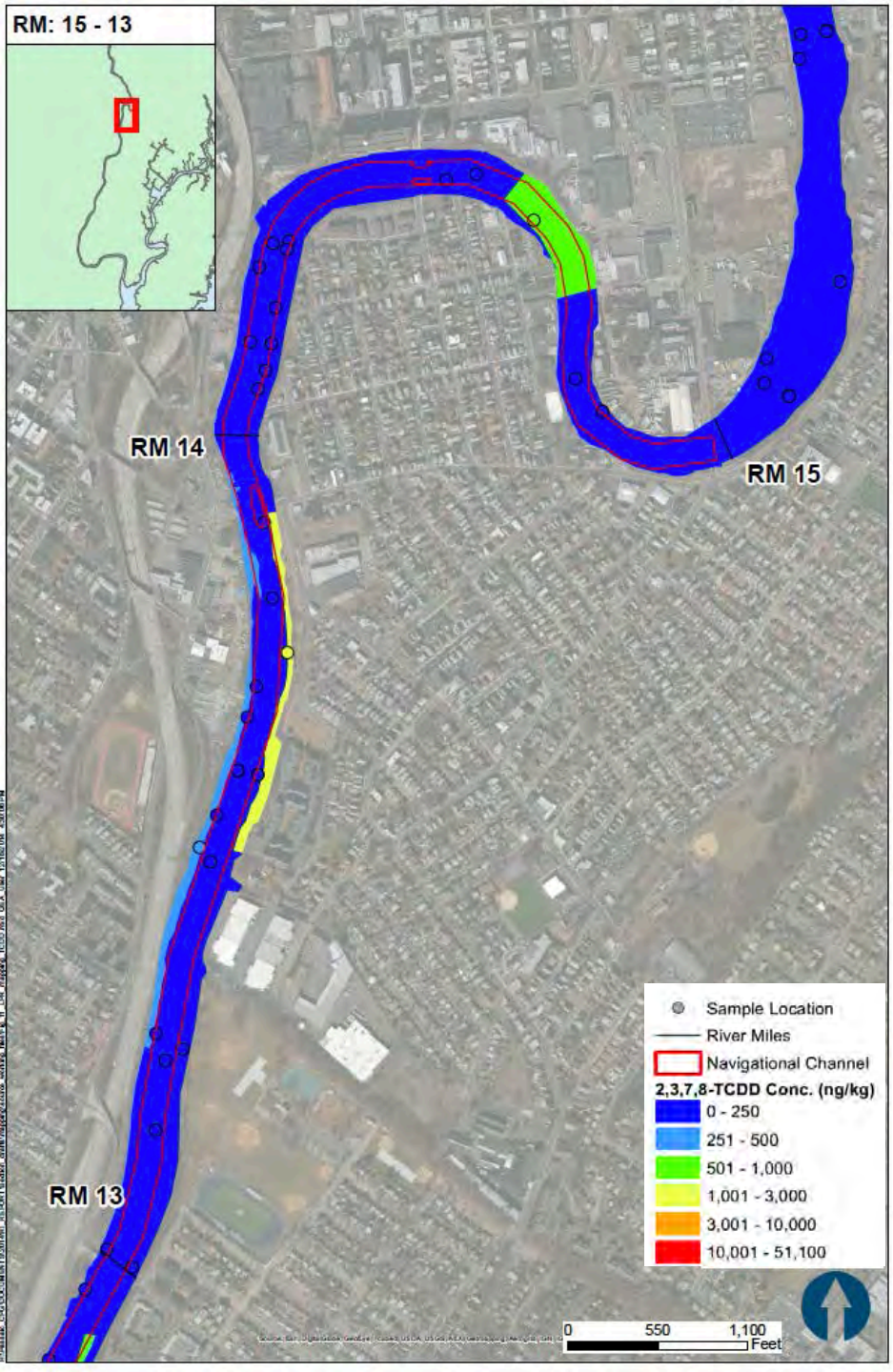

RM: 4.5 - 3.5
RM 4
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
625
1,250
Feet

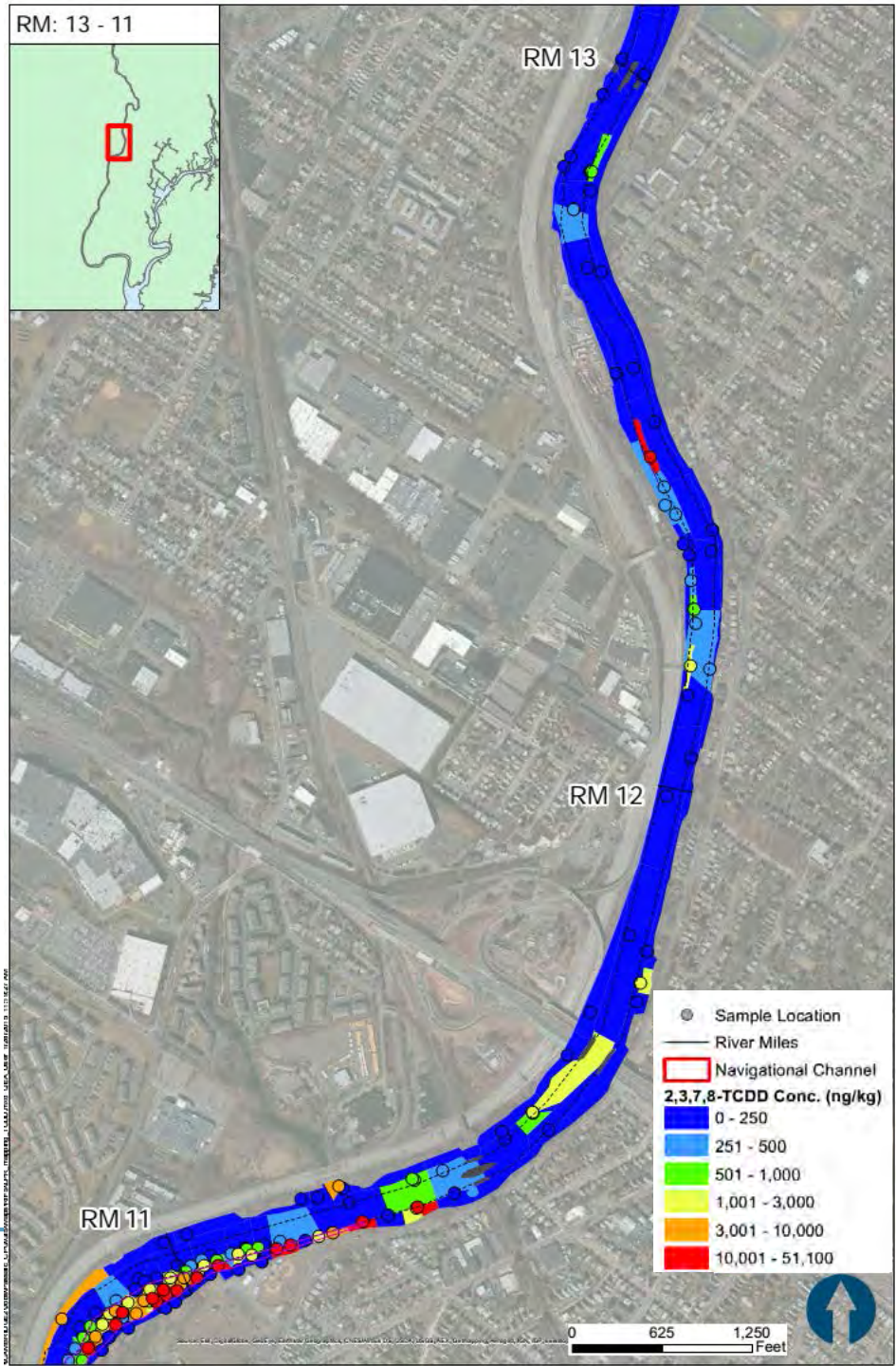

RM: 4.5 - 3.5
RM 4
Sample Location
River Miles
Navigational Channel
Total PCB Conc. (mg/kg)
0 - 1
1 - 2
2 - 4
4 - 6
6 - 8
> 8
0
625
1,250
Feet

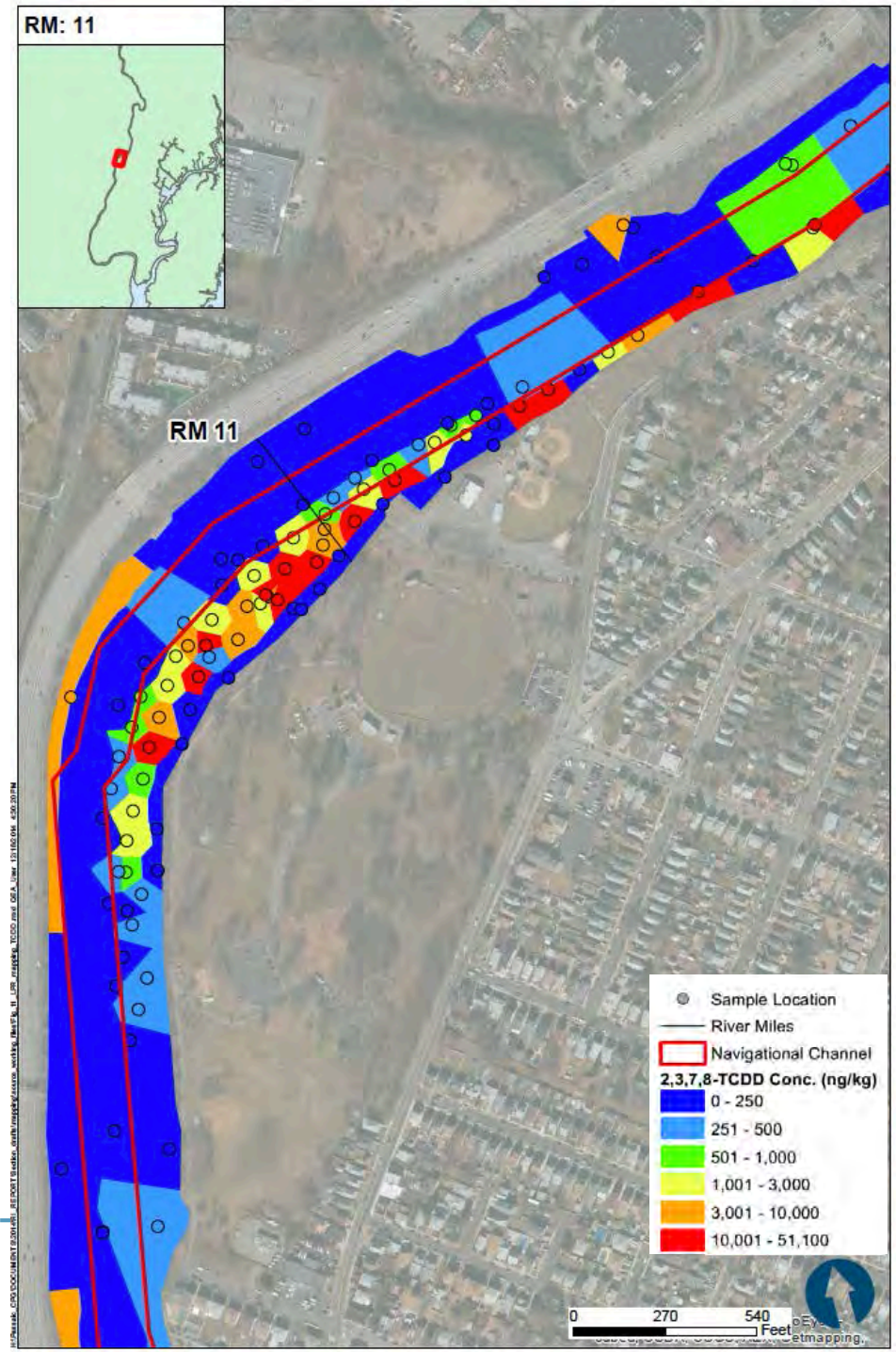
Conclusions

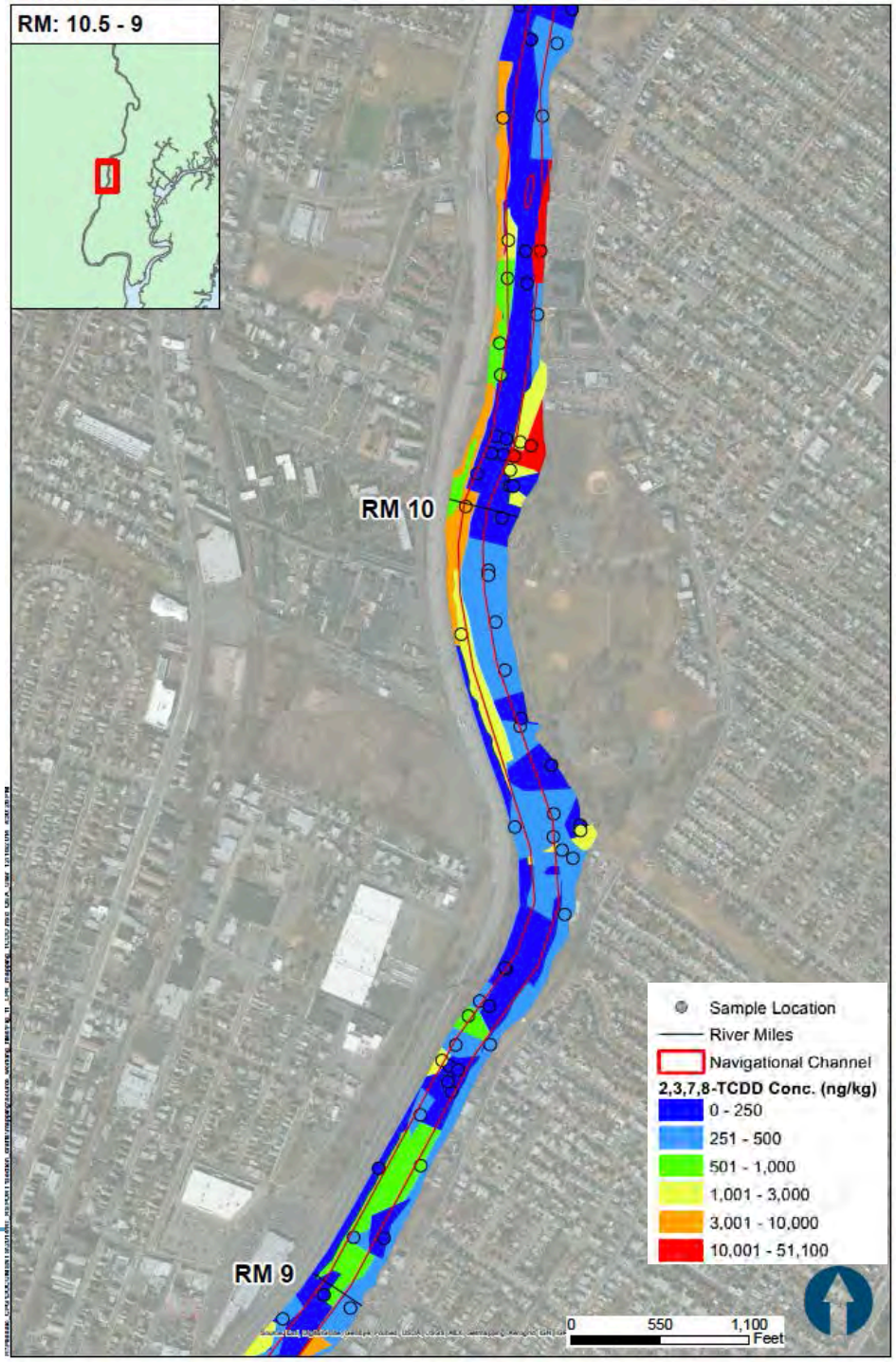
- Organized patterns support mapping of concentrations based on interpolation among the point measurements
  - Areas of high and low sediment contamination are identifiable (though not the precise concentration) and related to
    - Long-term deposition patterns
    - Geomorphology
    - Recent erosion/deposition
  - Concentrations tend to be higher at locations where sediments deposited between 1949 and the mid-1960s are within the top 6 inches today
- Thiessen polygon interpolation has strong precedent and is favored because it preserves the distribution of concentrations in the river

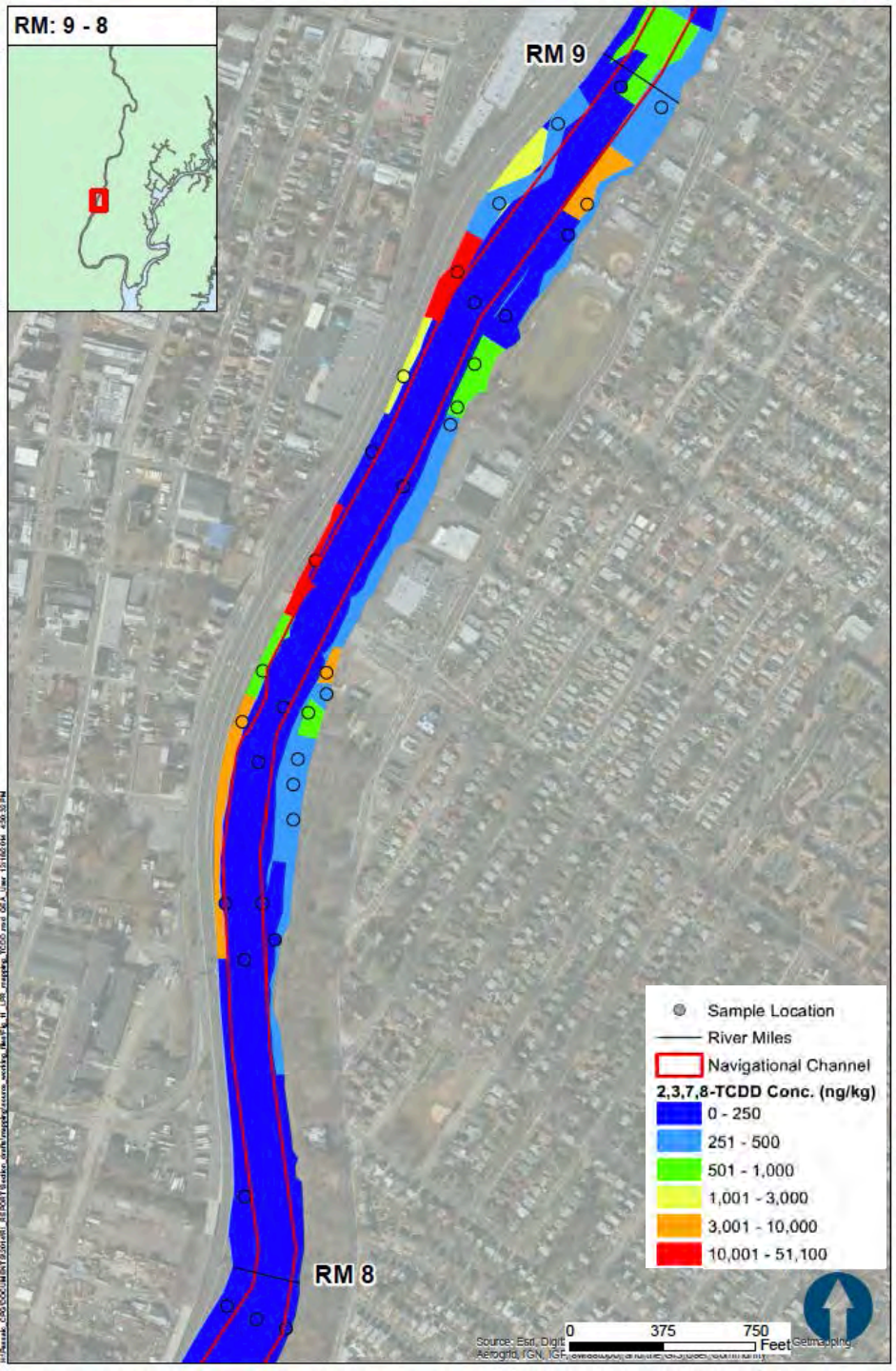
Backup

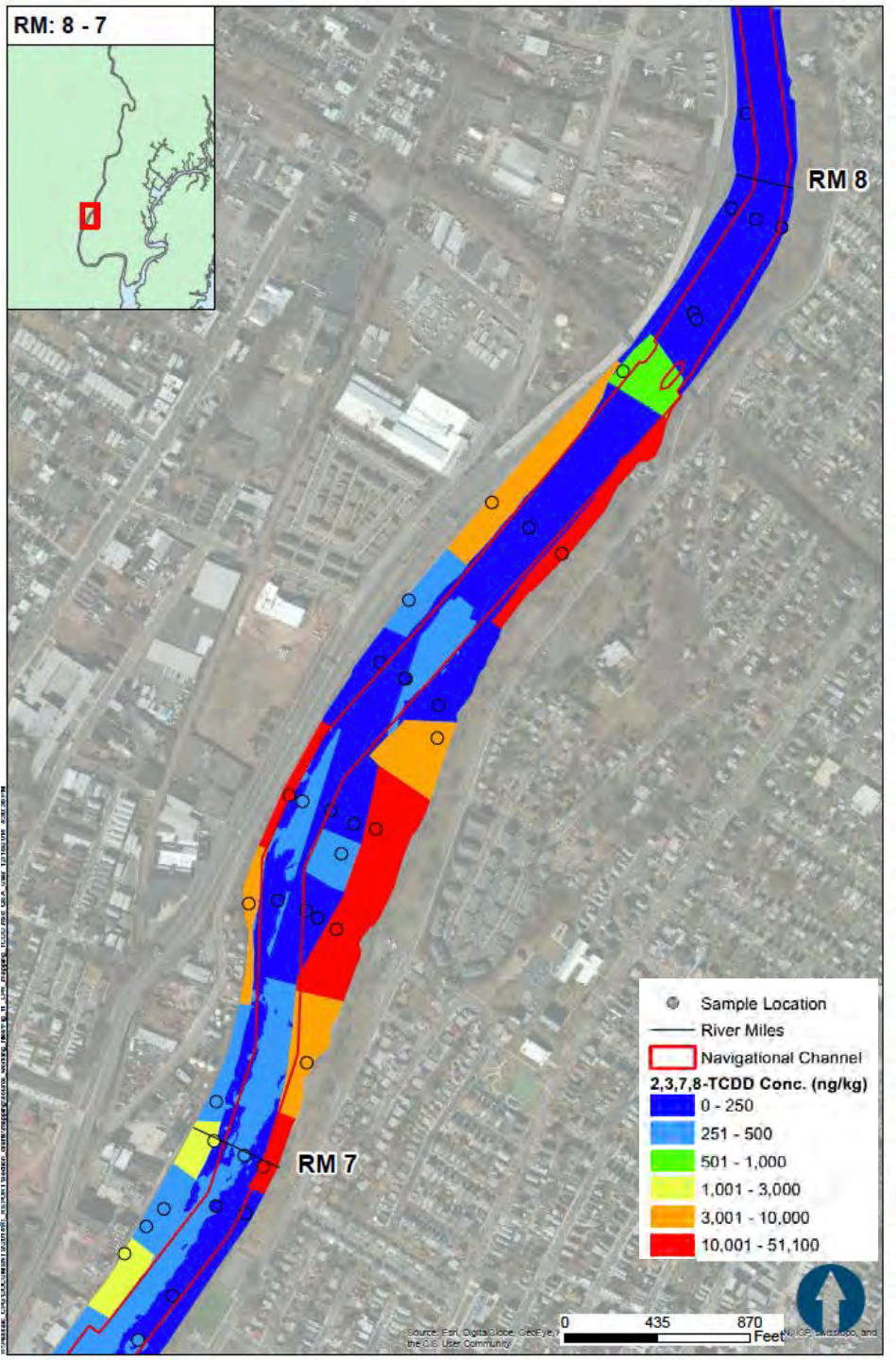

RM: 15 - 13
RM 14
RM 15
RM 13
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
550
1,100
Feet

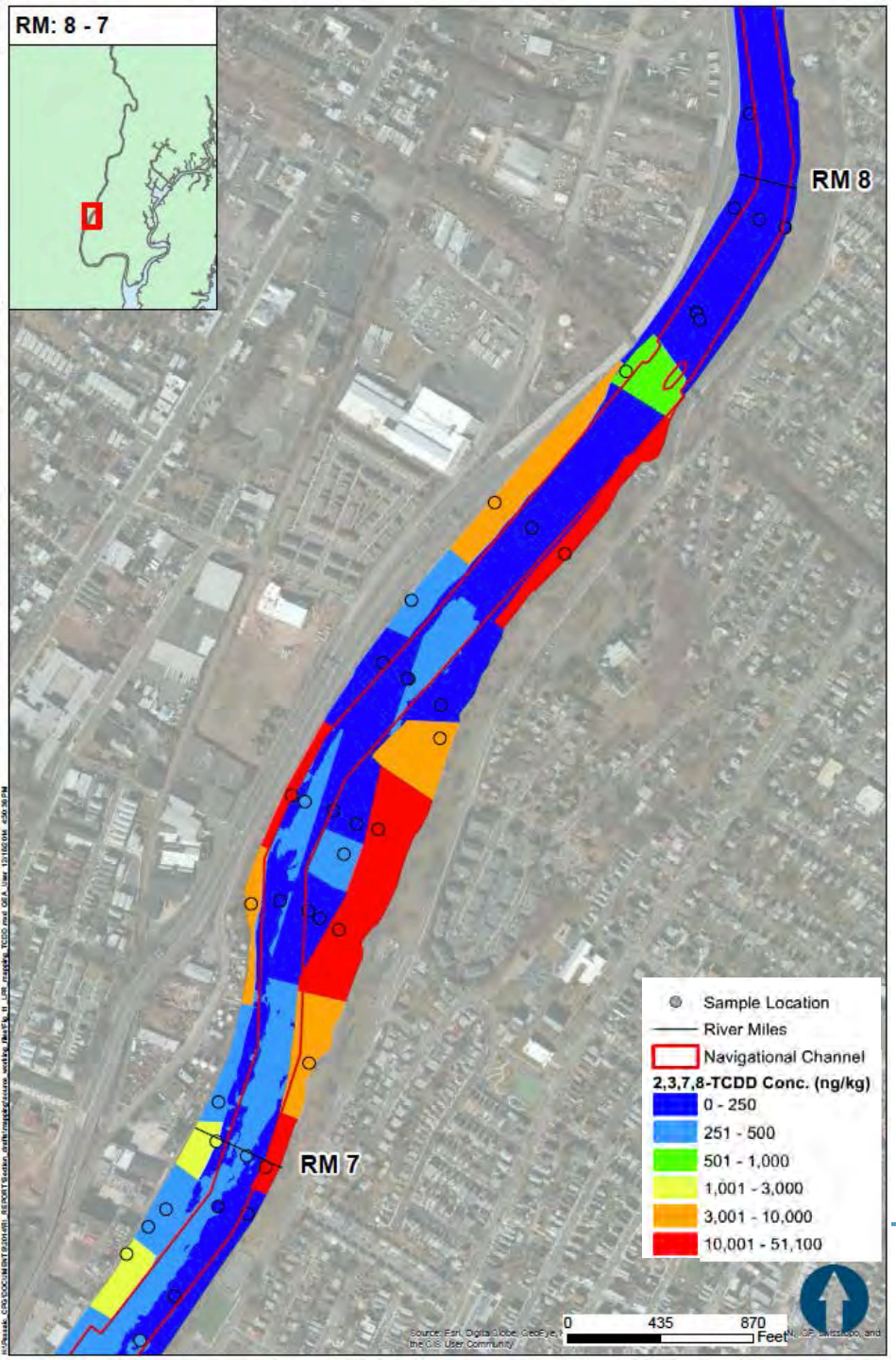

RM: 13 - 11
RM 13
RM 12
RM 11
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
625
1,250
Feet

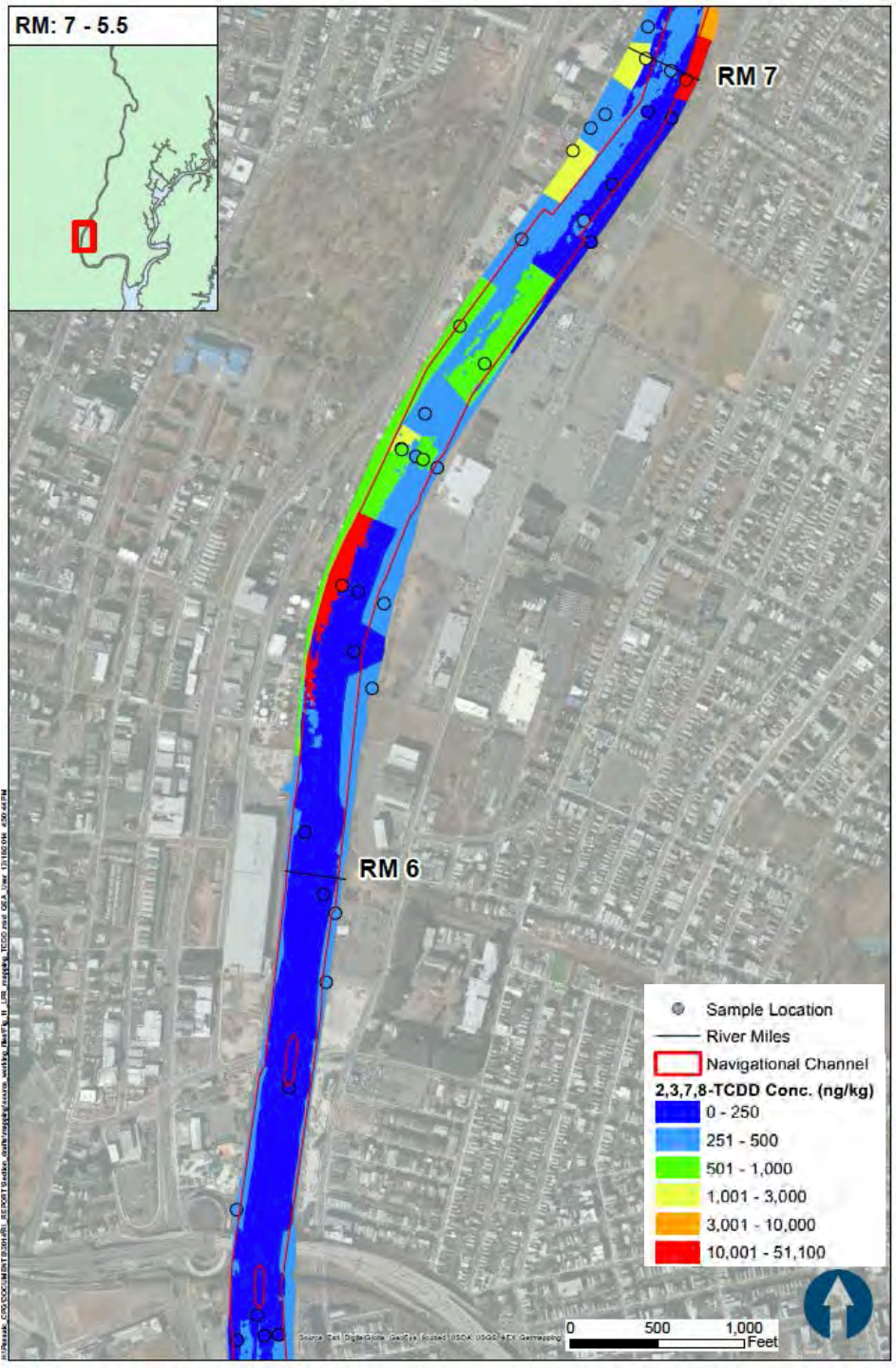

RM: 11
RM 11
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
270
540
Feet

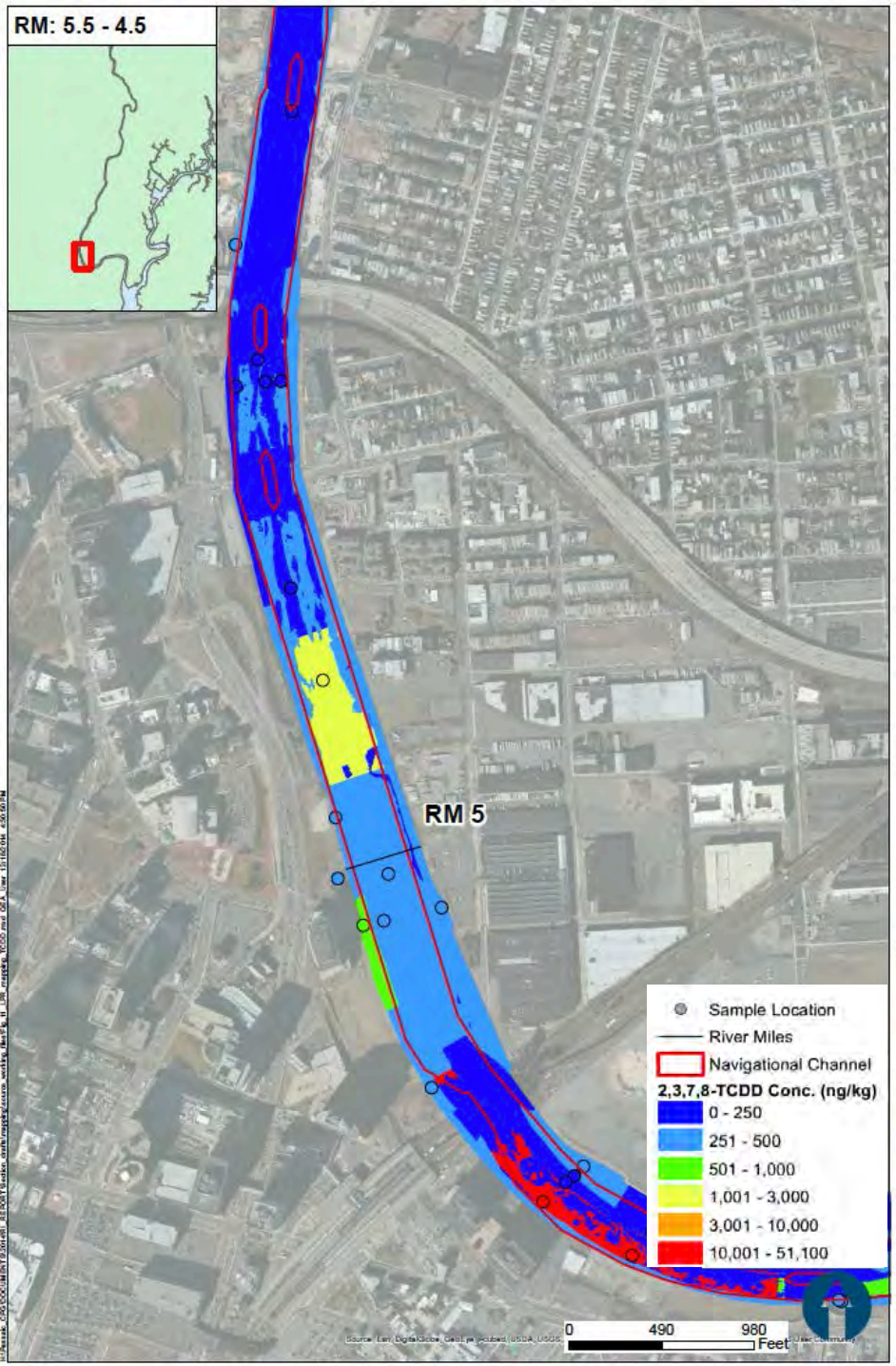

RM: 10.5 - 9
RM 10
RM 9
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
550
1,100
Feet

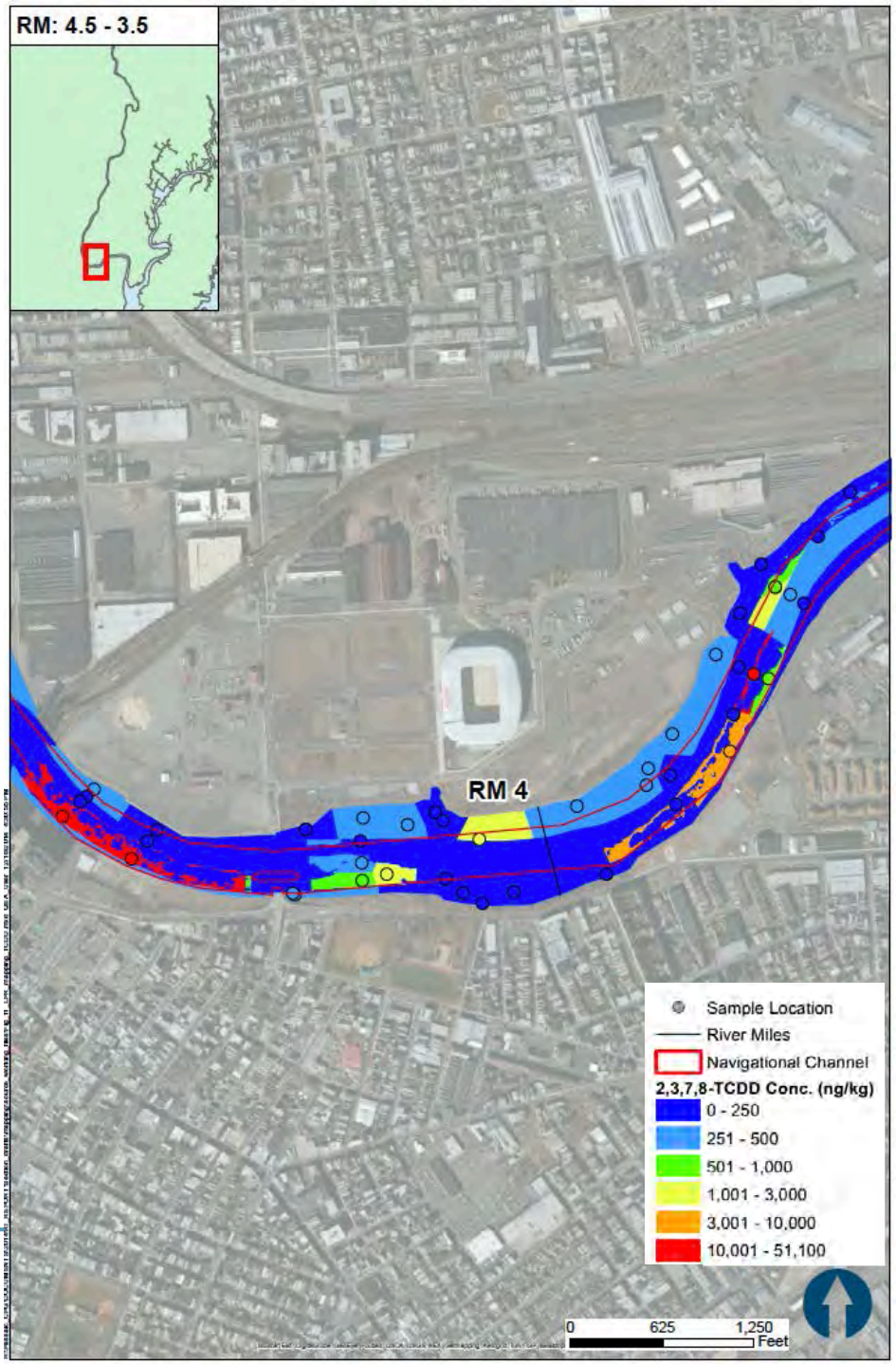

RM: 9 - 8
RM 9
RM 8
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0 375 750
Feet

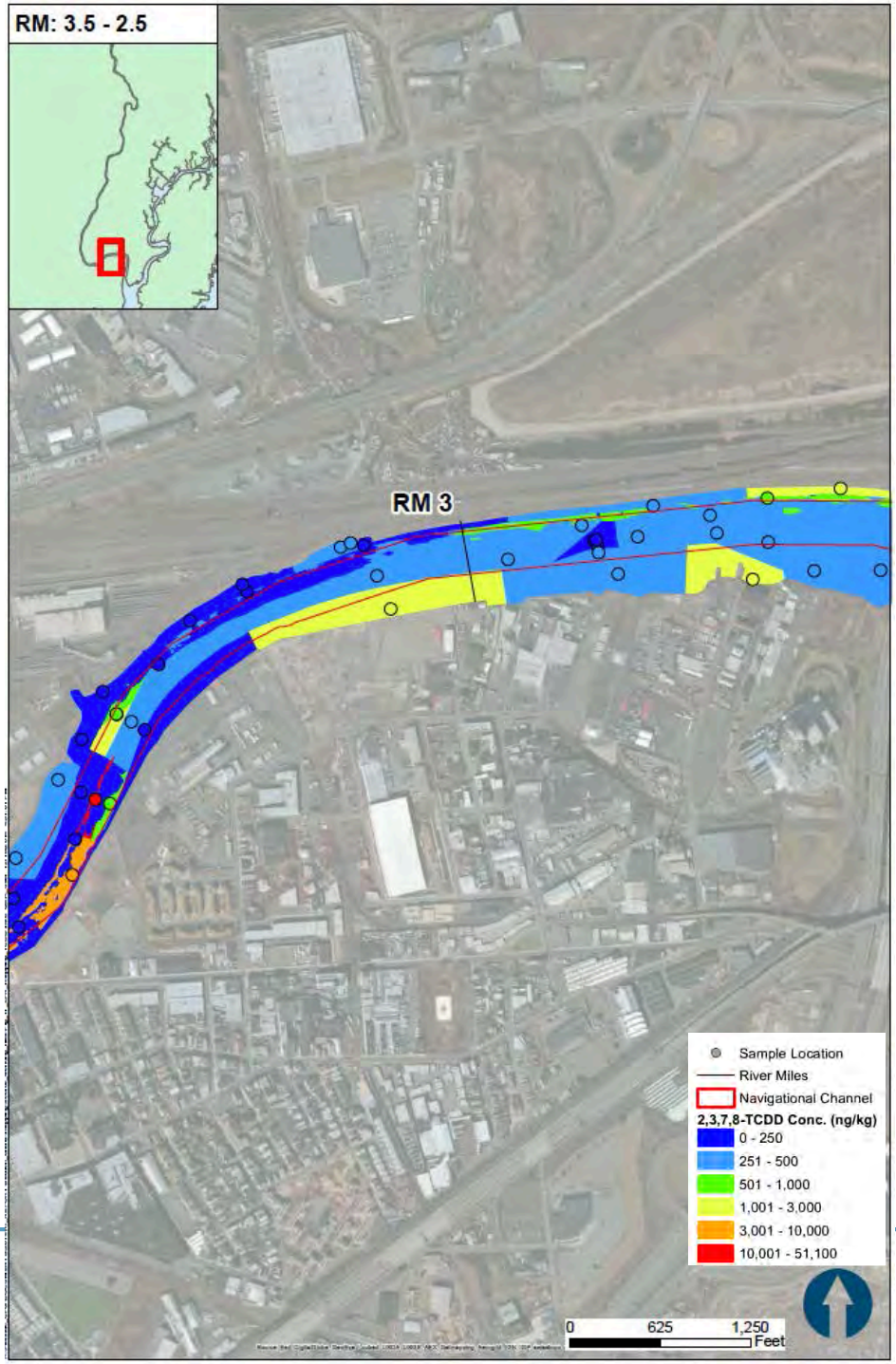

RM: 8 - 7
RM 8
RM 7
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0 435 870
Feet

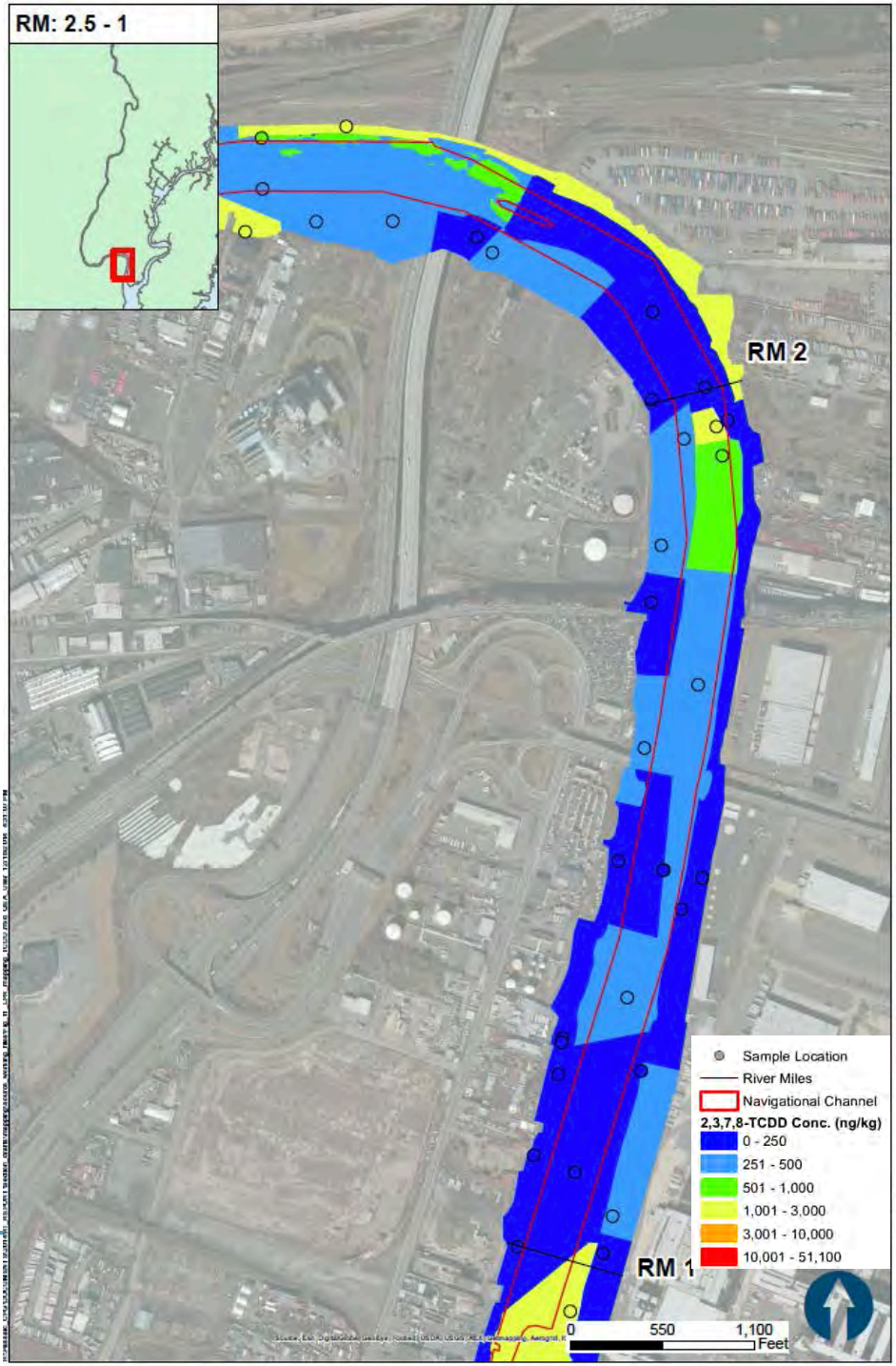

RM: 8 - 7
RM 8
RM 7
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
435
870
Feet


RM: 7 - 5.5
RM 7
RM 6
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
500
1,000
Feet


RM: 5.5 - 4.5
RM 5
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
490
980
Feet


RM: 4.5 - 3.5
RM 4
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
625
1,250
Feet


RM: 3.5 - 2.5
RM 3
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
625
1,250
Feet


RM: 2.5 - 1
RM 2
RM 1
Sample Location
River Miles
Navigational Channel
2,3,7,8-TCDD Conc. (ng/kg)
0 - 250
251 - 500
501 - 1,000
1,001 - 3,000
3,001 - 10,000
10,001 - 51,100
0
550
1,100
Feet